Total Maximum Daily Load Development for Mossy Creek and Long Glade Run: Bacteria and General Standard (Benthic) Impairments

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

Located in Rockingham and Augusta County, Virginia, the Mossy Creek (VAV-B19R, 10,077 acres) and Long Glade Run watersheds (VAV-B24R, 11,781 acres) share a boundary mostly centered on Route 42. They are located southwest of Harrisonburg and north of Staunton. Mossy Creek and Long Glade Run are both tributaries of the North River (USGS Hydrologic Unit Code 02070005), which in turn, is a tributary of the South Fork of the Shenandoah River. The Shenandoah River flows into the Potomac River. The Potomac River discharges into the Chesapeake Bay. Mossy Creek is a spring-fed premier trout stream.

1.2. Bacteria Impairment

1.2.1. Background

Water quality samples collected in Mossy Creek over a period of 10 ½ years (1992 –2003) indicated that 51% of the samples violated the instantaneous water quality standard for fecal coliform. Water quality samples collected in Long Glade Run over a period of 6 ½ years (1996 –2003) indicated that 24% of the samples violated the instantaneous water quality standard for fecal coliform. The instantaneous freshwater water quality standard for fecal coliform under which the Mossy Creek and Long Glade Run impairments were listed specified that fecal coliform concentration in the stream water shall not exceed 1,000 colony forming units (cfu) per 100 mL. Due to the frequency of water quality violations, both Mossy Creek and Long Glade Run were placed on Virginia’s 1996 303(d) list of impaired water bodies for fecal coliform. They have been assessed as not supporting the Clean Water Act’s Swimming Use Support Goal for the 1996

305(b) report. The impairment starts at the headwaters of both streams and continues downstream to their confluence with the North River. This includes a total of 9.65 stream miles for Mossy Creek and a total of 10.7 stream miles for Long Glade Run.

In order to remedy the fecal coliform water quality impairment, a Total Maximum Daily Load (TMDL) has been developed, taking into account all sources of bacteria and a margin of safety (MOS). The TMDL was developed for the new water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL, and that no single sample can exceed a concentration of 235 cfu/100mL. A glossary of terms used in the development of this TMDL is listed in Appendix A.

1.2.2. Sources of Bacteria

There is one small (1,000 gpd) source permitted to discharge bacteria in the Mossy Creek watershed and three small sources permitted to discharge bacteria in the Long Glade Run watershed; however, the majority of the bacteria load originates from nonpoint sources. The nonpoint sources of bacteria are mainly agricultural and include land-applied animal waste and manure deposited on pastures by livestock. A significant bacteria load comes from cattle and wildlife directly depositing feces in streams. Wildlife also contribute to bacteria loadings on all land uses, in accordance with the habitat range for each species. Non-agricultural nonpoint sources of bacteria loadings include failing septic systems and pet waste. The amounts of bacteria produced in different locations (e.g., confinement, pasture, forest) were estimated on a monthly basis to account for seasonal variability in wildlife behavior and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement, pastures, or streams; the amount of manure storage; and spreading schedules for manure application, were considered on a monthly basis. In Mossy Creek, there are also four springs that contribute small amounts of fecal coliform to the creek.

1.2.3. Modeling

The Hydrologic Simulation Program – FORTRAN (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Mossy Creek and Long Glade Run watersheds. To identify localized sources of fecal coliform within the Mossy Creek and Long Glade Run watersheds, Mossy Creek was divided into 8 sub-watersheds and Long Glade run into 9 sub-watersheds, based primarily on homogeneity of land use.

The hydrology component of HSPF was calibrated and validated separately for Mossy Creek and Long Glade Run. The HSPF model was calibrated for Mossy Creek using data from a 1-year, 4-month period and for Long Glade Run using data from an 11-month period. Due to the limited quantity of suitable data, both calibration periods encompassed a period of unusual drought, with few high flow events. The calibrated HSPF model was validated on a separate period of record for Mossy Creek (1 year, 9 months). Due to insufficient data, the Long Glade Run model was not validated for hydrology. The calibrated HSPF models adequately simulated the hydrology of the Mossy Creek and Long Glade Run watersheds.

The water quality component of the HSPF model was calibrated for Mossy Creek using 3 years (January 1999 – December 2001) of fecal coliform data collected in the watershed and for Long Glade Run using 11 months (September 1999 - July 2000) of fecal coliform data collected in the watershed. Inputs to the model included fecal coliform loadings on land and in the stream and simulated flow data. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the respective models adequately simulated the fate and transport of fecal coliform in each watershed.

1.2.4. Margin of Safety

A margin of safety (MOS) is included to account for any uncertainty in the TMDL development process. There are several different ways that the MOS could be incorporated into the TMDL (USEPA, 1991). For Mossy Creek and

Long Glade Run, the MOS was implicitly incorporated into each TMDL by conservatively estimating several factors affecting bacteria loadings, such as animal numbers, bacteria production rates, and contributions to streams.

1.2.5. Existing Conditions

Contributions from various sources from the Mossy Creek watershed were represented in HSPF to establish the existing conditions for the representative period of 3 years. Thirty-four percent of the fecal coliform in the mean daily fecal coliform concentration comes from cattle directly depositing in the stream, 61% from upland areas due to runoff, 2% comes from wildlife directly depositing in the stream, 1% from bacteria in springs, and a remaining 2% accounted for by straight pipes, runoff from impervious areas, and contributions from interflow and groundwater.

Contributions from various sources from the Long Glade Run watershed were represented in HSPF to establish the existing conditions for the representative period of 3 years. Sixty percent of the fecal coliform in the mean daily fecal coliform concentration comes from cattle directly depositing in the stream, 37% from upland areas due to runoff, 3% comes from wildlife directly depositing in the stream, and the remaining 1% is accounted for by runoff from impervious areas.

For both watersheds, simulated bacteria concentrations exceeded the calendar-month geometric mean water quality standard at all times, but by a greater amount during low flow periods and the summer. During the summer when stream flow is lower, cattle tend to spend more time in streams, increasing direct fecal coliform deposition to streams when water for dilution is least available.

1.2.6. TMDL Allocations and Stage 1 Implementation

Based on amounts of bacteria produced in different locations, monthly bacteria loadings to different land use categories were calculated for each sub-watershed in each watershed for input into the respective models. Bacteria content of stored waste was adjusted to account for die-off during storage prior to land application. Similarly, bacteria die-off on land was taken into account, as was the reduction in bacteria available for surface wash-off due to incorporation following waste application on cropland. Direct seasonal bacteria loadings to streams by cattle were calculated for pastures adjacent to streams. Bacteria loadings to streams and land by wildlife were estimated for several species. Bacteria loadings to land from failing septic systems were estimated based on number and age of houses. Bacteria contribution from pet waste was also considered.

When developing a bacteria TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface; these reductions are presented in the tables in Sections 1.2.7 and 1.2.8. In the model, this has the effect of reducing the amount of bacteria that reaches the stream, the ultimate goal of the TMDL. Thus, the reductions called for in Sections 1.2.7 and 1.2.8 indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown in Sections 1.2.7 and 1.2.8 are not intended to infer that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (cattle direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions for from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, and other appropriate measures included in the TMDL Implementation Plan.

For the TMDL allocation scenarios, a target of zero violations of both the instantaneous and geometric mean water quality standards was used. For the Stage 1 implementation scenario, a target of zero reductions in wildlife and 10% violation of the instantaneous standard was used.

1.2.7. Allocation Scenarios for Mossy Creek

After calibrating to the existing water quality conditions, different source reduction scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.1.

Table 1.1. Allocation scenarios for the Mossy Creek watershed.

Scenario Number	% Violation of *E. coli* standard		Required Fecal Coliform Loading Reductions to Meet the *E coli* Standards,%						
	Geomean	Single Sample	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	Straight Pipes	All Residential PLS
Existing Conditions	100%	48%	0	0	0	0	0	0	0
1	97%	41%	0	50	50	100	0	100	50
2	0.0%	0.1%	94	95	97	100	0	100	95
3	0.0%	0.1%	94	95	95	100	30	100	95
4	0.0%	0.1%	99	95	95	100	99	100	95
5	0.0%	0.0%	99	90	98	100	30	100	95
6	0.0%	0.0%	94	95	98	100	0	100	95

In scenario 01, straight-pipes were eliminated and large reductions (at least 50%) were taken from land surface loads (cropland, pasture, loafing lots, and residential). This had little effect, decreasing the violations of the geometric mean standard and the instantaneous standard by 3% and 7%, respectively (Table 1.1). Scenarios 02 through 04 took increasing reductions from all sources while still not meeting the standard. The progression from Scenario 02 to the successful scenarios (Scenarios 05 and 06) shows that high reductions are required from PLS areas. Scenario 03 illustrates that a high reduction in cattle direct-deposit will be required. Scenario 04 illustrates that increasing the wildlife direct-deposit reduction to an extreme level (99%) will not produce a viable source reduction scenario without additional reductions from the other sources. Scenarios 05 and 06 both meet the *E. coli* standard. It should be noted that the cattle and wildlife direct-deposit source reductions are less in Scenario 06 than in Scenario 05, but the cropland reduction is greater. Scenario 06 was selected as the TMDL allocation because it calls for lower reductions for wildlife direct-deposit than Scenario 05.

The required load reductions for the TMDL allocation for wet weather nonpoint sources are listed in Table 1.2 and for direct nonpoint sources in Table 1.3. The calendar-month geometric mean fecal coliform concentrations resulting from Scenario 06, as well as the existing conditions, are presented graphically in Figure 1.1.

Table 1.2. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for the successful TMDL allocation scenario (Scenario 06).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	666	1%	33.3	95%
Pasture	51,500	97%	1,030	98%
Residential[a]	238	<1%	11.9	95%
Loafing Lot	852	2%	0	100%
Forest	103	<1%	103	0%
Total	53,600	100%	1,170	98%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 1.3. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for the successful TMDL allocation scenario (Scenario 06).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction
Cattle in streams	189	89%	11.3	94%
Straight Pipes	3.40	2%	0	100%
Wildlife in Streams	12.5	6%	12.5	0%
Spring Contributions	6.7	3%	6.7	0%
Total	212	100%	30.5	86%

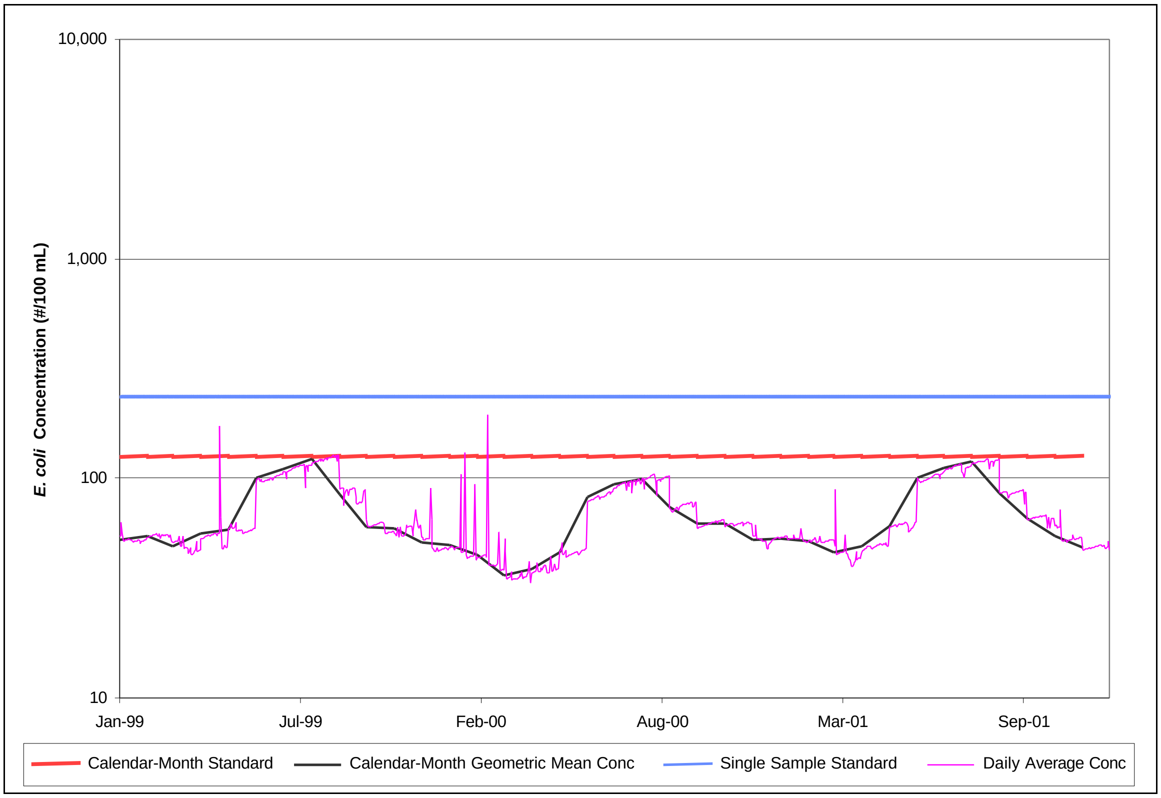

Figure 1.1. Successful *E. coli* TMDL allocation, 126 cfu/100mL geometric mean goal, and 235 cfu/100mL single sample goal for Mossy Creek (Scenario 06, Table 1.1).

Using Equation [1.1], the TMDL allocation was calculated as shown in Table 1.4.

TMDL = SWLA + SLA + MOS [1.1]

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, implicit.

There is one small point source discharging at or below its permit requirements; therefore, the proposed scenario requires load reductions only for nonpoint sources of fecal coliform. The TMDL load was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenario. In Table 1.4, the WLA was obtained by taking the product of the permitted point source's *E. coli* discharge concentration and allowable annual discharge. The LA is then determined as the TMDL-WLA.

Table 1.4. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Mossy Creek bacteria TMDL.

Parameter	SWLA	SLA	MOS[a]	TMDL
E. coli	1.74×10^9 *(VAG401083=1.74×10^9)*	$15,919 \times 10^9$	--	$15,921 \times 10^9$

[a] Implicit MOS

The proposed scenario requires a 95% to 100% reduction in bacteria loads to all land uses except forest and a 92% reduction from livestock direct-deposits to streams to meet the *E. coli* standard. Further, complete elimination of discharge from direct pipes to the stream is required to meet the TMDL goal.

1.2.8. Allocation Scenarios for Long Glade Run

After calibrating to the existing water quality conditions, different source reduction scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. The scenarios are presented in Table 1.5.

Table 1.5. Allocation scenarios for Long Glade Run watershed.

	% Violation of *E. coli* Standard		Fecal Coliform Loading Reduction Required to Meet the *E coli* Standards, %					
Scenario Number	Geomean	Single Sample	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	All Residential PLSs
Existing Conditions	100%	57%	0	0	0	0	0	0
1	94%	45%	50	50	50	50	0	50
2	6%	0%	100	100	100	100	0	100
3	0%	0.07%	99	90	90	99	50	99
4	3%	0%	97	95	95	100	35	95
5	3%	0%	99	95	95	100	25	85

6	0%	0.07%	99	95	95	100	30	25
7	0%	0%	98	95	95	100	35	30
8	0%	0%	100	95	95	100	25	30
9	0%	0%	99	95	95	100	30	30

In all the proposed scenarios, reductions in wildlife direct-deposit to streams were minimized to ensure a practically implementable scenario. An initial attempt at moderate reductions (50% for all source categories except wildlife, Scenario 01) yielded only a 6% reduction in the geometric mean violation rate and a 12% reduction in the instantaneous violation rate, indicating that extreme reductions would likely be necessary to meet the water quality standard. For this watershed, it is impossible to meet the water quality standard without wildlife direct-deposit reductions. Large reductions (≥ 95%) in cropland and pasture loadings are also required to meet the standard. The necessity of the large (≥ 98%) cattle direct-deposit source reductions is evident beginning with Scenario 02. The three successful source reduction scenarios (07 – 09) all indicated the need for reductions from the residential PLSs. These successful scenarios also illustrate the tradeoff between the cattle and wildlife direct-deposit source categories. While Scenarios 07 through 09 all met both the geometric mean and the single sample standards for *E. coli*, Scenario 09 was selected as reductions in wildlife direct-deposit are minimized without calling for the complete elimination of livestock direct deposit. All successful scenarios called for large reductions in the loafing lot loadings to streams.

The required load reductions for the TMDL allocation for wet weather nonpoint sources are listed in Table 1.6 and direct nonpoint sources in Table 1.7. The calendar-month geometric mean fecal coliform concentrations resulting from Scenario 09, as well as the existing conditions, are presented graphically in Figure 1.2.

Table 1.6. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 09).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	572	1%	28.6	95%
Pasture	48,700	96%	2,440	95%
Residential[a]	206	<1%	144	30%
Loafing Lot	1,140	2%	0	100%
Forest	92.3	<1%	92.3	0%
Total	50,700	100%	2,700	95%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 1.7. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 09).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cattle in streams	55.7	96%	0.557	99%
Wildlife in Streams	2.53	4%	1.77	30%
Total	58.2	100%	2.33	96%

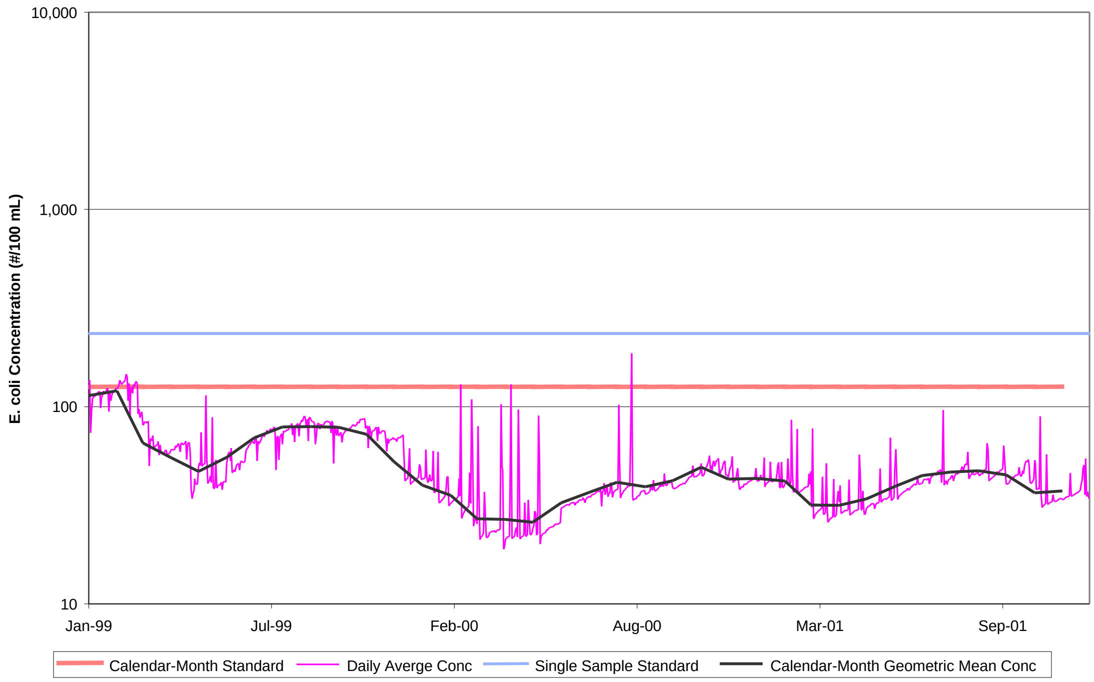

Figure 1.2. Successful *E. coli* TMDL allocation, 126 cfu/100mL geometric mean goal, and 235 cfu/100mL single sample goal for Long Glade Run (Scenario 09, Table 1.5).

For the selected scenario (Scenario 09), load allocations were calculated using the following equation.

$$TMDL = \sum LA + \sum LA + MOS \qquad [1.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety, implicit.

There are three small point sources of bacteria that are discharging at or below their permit requirements in the Long Glade Run watershed; therefore, the proposed scenario requires load reductions only for nonpoint sources of fecal coliform. In Table 1.8, the WLA was obtained by summing the products of each permitted point source's *E. coli* discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 1.8. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Long Glade Run bacteria TMDL.

Parameter	SWLA	SLA	MOS[a]	TMDL
E. coli	5.23×10^9 *(SSFH WLA = $5.23*10^9$)*	$2,315 \times 10^9$	--	$2,320 \times 10^9$

[a] Implicit MOS

The proposed scenario requires a 95% to 100% reduction in bacteria loads to all land uses except forest and a 30% reduction from wildlife direct-deposits to streams to meet the *E. coli* standard. Further, there must be a 99% reduction in contributions from cattle in streams to meet the TMDL goal.

1.2.9. Stage 1 Implementation

An alternative scenario was evaluated to establish a first stage for the implementation of the TMDL. The implementation of such a transitional scenario, or Stage 1 implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection. Stage 1 implementation was developed for a maximum of 10% violation rate of the single sample *E. coli* water quality standard (235 cfu/100 mL), based on daily average of the simulated concentrations. In addition, the Stage 1 scenario was designed without reductions from wildlife.

<u>1.2.9.a. Mossy Creek</u>

Stage 1 implementation for the Mossy Creek watershed requires an 85% reduction in direct loading by cattle in-stream. An 85% reduction in loadings from the pasture upland areas is required. Reductions of 75% are needed for loads to loafing lots. Reductions in loads from cropland, residential areas, and wildlife direct deposit in the stream are not required. Complete elimination of illegal straight pipe dischargers is necessary.

1.2.9.b. Long Glade Run

Stage 1 implementation for the Long Glade Run watershed requires a 90% reduction in direct loading by cattle in-stream and elimination of direct discharge by direct pipes. Also, a 65% reduction in loadings from the cropland, pasture, and loafing lot upland areas is required. No reduction in loads from residential areas or from wildlife directly depositing in the stream is required.

1.3. Benthic Impairment

1.3.1. Background

The same 9.65 mile Mossy Creek stream segment placed on the 303(d) list in 1998 for a bacteria impairment was also listed for a benthic impairment by the plaintiffs in Virginia's consent decree. VADEQ's 2002 Impaired Waters Fact Sheet states that "biological monitoring indicated Full Use Support in 1998, 2000, and 2002". In each of these assessment periods, the overall assessment was "slightly impaired", which is interpreted as a full use support. A check of individual sample ratings during each of the respective assessment periods, however, showed 4/6, 4/8, and 3/8 "moderately impaired" ratings, and again for the 2004 assessment period, 2/5 "moderately impaired" ratings. In each of the assessment periods at least two of the "moderate" ratings were given to consecutive samples, except during the 2002 assessment period. For these reasons, the Mossy Creek watershed was retained on the 303(d) list and a TMDL is required for this moderate to slight impairment.

1.3.2. Benthic Stressor Analysis

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on physical and chemical water quality parameters, the pollutant is not implicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in the United States Environmental Protection Agency's (USEPA)

Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Mossy Creek.

After analyzing the available data for Mossy Creek watershed, no single unambiguous stressor emerged during the stressor analysis. After discussion with the regional DEQ TMDL coordinator and biologist, and state DEQ and DCR personnel, sediment was selected as the most probable stressor in Mossy Creek. The evidence supporting sediment included recent declining trends in habitat scores related to sediment – embeddedness, channel alterations, and in-stream sediment point bars, the larger TSS concentrations observed with runoff events, and streambank erosion related to livestock access. Since many best management practices (BMPs) employed to control sediment result in decreases in the other possible stressors (i.e., nutrients and organics) as well, and since a staged implementation approach is being used to address benthic impairments in Virginia, the choice of sediment was judged to be the most logical. The ultimate criteria for judging the success of the TMDL will be the restoration of the benthic community itself.

1.3.3. Sources of Sediment

Sediment is delivered to the impaired segments of Mossy Creek through the processes of surface runoff, and from channel and streambank erosion, as well as from background geologic processes. Natural sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, and residential land uses. During runoff events, sediment loading occurs from both pervious and impervious surfaces in the watershed. Streambank erosion is caused by channel alterations and reductions in riparian cover resulting in streambank instability and increased runoff rates. Animals grazing on pastures in riparian areas with access to streams also contribute to the instability of streambanks in those areas.

1.3.4. Modeling

The TMDL to address the benthic impairment in Mossy Creek was developed using sediment as the pollutant. Because Virginia has no numeric in-stream criteria for sediment, a “reference watershed” approach was used to set allowable loading rates in the impaired watershed. The reference watershed approach pairs two watersheds: one whose streams are supportive of their designated uses, and one whose streams are impaired. The Upper Opequon Creek watershed was selected as the TMDL reference watershed for Mossy Creek. Land use distribution was considered the most important characteristic considered in this comparison, with both watersheds dominated by agricultural land uses.

The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was selected for comparative modeling of both the impaired and TMDL reference watersheds in this TMDL study. A GWLF model of each watershed was calibrated separately for hydrology. Channel erosion was modeled explicitly within GWLF using the algorithms included in the AVGWLF adaptation of the GWLF model (Evans et al., 2001).

1.3.5. Margin of Safety

The margin of safety (MOS) was explicitly modeled as 10% of the calculated TMDL to reflect the relative degree of accuracy expected from paired watershed modeling with GWLF.

1.3.6. Benthic TMDL for Sediment

The TMDL to address the benthic impairment in Mossy Creek was developed using sediment as the pollutant and the Upper Opequon watershed as the TMDL reference watershed. The land area in Mossy Creek watershed (4,071 ha) is less than the land area in the Upper Opequon Creek watershed (14,832 ha). In order to establish a common basis for comparing loads between these two watersheds, each land use category in the Upper Opequon Creek watershed was proportionally decreased to create an area-adjusted Upper Opequon Creek watershed, equal in size with the Mossy Creek watershed, while maintaining its original land use distribution. TMDL modeling was then performed on the equal-area watersheds to generate sediment loads for comparison using a common 15-yr period of weather inputs (January 1984 – December 1999) as representative of the normal expected range of local weather conditions. The sediment loads for existing conditions were modeled for each watershed and are listed in Table 1.9 by land use category both as annual average loads (t/yr) and as unit area loads (t/ha) for individual land uses.

Table 1.9 Existing Sediment Loads

	Mossy Creek			Upper Opequon Creek		
Surface Runoff Sources	**(t/yr)**	**(t/ha-yr)**	**(%)**	**(t/yr)**	**(t/ha-yr)**	**(%)**
High Till	8,455.0	52.2	41.5%	1,825.2	14.6	32.1%
Low Till	9,166.5	23.0	45.0%	826.7	8.7	14.6%
Pasture	1,358.0	0.5	6.7%	730.1	0.4	12.9%
Urban grasses	0.0	0.0	0.0%	113.3	1.2	2.0%
Orchards	0.0	0.0	0.0%	16.0	0.1	0.3%
Forest	96.4	0.1	0.5%	79.9	0.1	1.4%
Transitional	16.5	9.2	0.1%	289.1	15.0	5.1%
Pervious Urban	65.1	0.5	0.3%	49.1	0.2	0.9%
Impervious Urban	0.0	0.0	0.0%	120.8	0.6	2.1%
Other Sources						
Channel Erosion	1,227.2		6.0%	1,628.2		28.7%
Point Sources	0.04		0.0%	2.5		0.0%
Watershed Totals						
Existing Sediment Load (t/yr)	20,385.0			5,680.8		
Area (ha)	4,071.2			4,071.2		
Unit Area Load (t/ha-yr)	5.007			**1.395**		
Target Sediment TMDL Load				**5,680.8**		**t/yr**

The sediment TMDL for Mossy Creek is comprised of three required components – WLA, LA, and MOS - as quantified in Table 1.10. The average annual sediment load in metric tons per year (t/yr) from the area-adjusted Upper Opequon Creek watershed (from Table 1.9) was used to define the TMDL sediment load for Mossy Creek. The margin of safety (MOS) was explicitly specified as 10% of the calculated TMDL. The waste load allocation (WLA) was included as the contribution from the one 1000-gpd housing unit covered under the general permit. And finally, the load allocation (LA) – the allowable sediment load from nonpoint sources – was calculated as the TMDL minus the MOS minus the WLA.

Table 1.10. Mossy Creek Sediment TMDL (t/yr)

TMDL	WLA	LA	MOS
5,680.8	0.04 VAG401083 = 0.04	5,112.6	568.1

1.3.7. TMDL Reductions and Allocations

Changes in future land use distribution and sediment sources were judged to be minimal, and were modeled as constant. The TMDL allocations, therefore, were based on existing land uses and sediment sources.

For development of the allocation scenarios, overland non-point sediment sources were grouped into the following four categories: Cropland, Pasture, Urban, and Forestry. Additionally, Channel Erosion and Point Sources were listed as separate categories. Three alternative allocation scenarios were developed to reduce existing sediment loads in Mossy Creek to the levels required by the TMDL, as illustrated in Table 1.11. Note that the allocation target load = TMDL –MOS.

Table 1.11. Alternative Load Reduction Scenarios

Source Category	Reference Upper Opequon (t/yr)	Existing Mossy Creek (t/yr)	TMDL Sediment Load Allocations: TMDL Alternative 1 (% reduction)	TMDL Alternative 1 (t/yr)	TMDL Alternative 2 (% reduction)	TMDL Alternative 2 (t/yr)	TMDL Alternative 3 (% reduction)	TMDL Alternative 3 (t/yr)
Cropland	2,667.9	17,621.5	86.7%	2,349.2	75.6%	4,303.2	74.9%	4,419.6
Pasture	730.1	1,358.0	0%	1,358.0	75.6%	331.6	74.9%	340.6
Urban	572.3	81.7	0%	81.7	0.0%	81.7	74.9%	20.5
Forestry	79.9	96.4	0%	96.4	0.0%	96.4	74.9%	24.2
Channel Erosion	1,628.2	1,227.2	0%	1,227.2	75.6%	299.7	74.9%	307.8
Point Sources	2.4	0.04	0%	0.04		0.04		0.04
Total	**5,680.8**	**20,385.0**		**5,112.7**		**5,112.7**		**5,112.7**

The sediment TMDL for Mossy Creek is 5,680.8 t/yr and will require an overall reduction of 74.9% from existing loads. From the three alternative scenarios explored, Alternative 3 is recommended as the most equitable approach as it requires equal % reductions from all source categories.

A concurrent bacteria TMDL requires an increased level of Livestock Exclusion from streams that directly affects the sediment loads from channel erosion in Mossy Creek. This reduction benefit was calculated as the product of the percentage of total stream length with livestock access, the percentage reduction of livestock access corresponding with the bacteria TMDL, and an estimated percentage of the channel erosion due to trampling, where livestock had stream access. Sediment load reductions amounting to 141.7 t/ha-yr, or 11.6% reduction of the existing Channel Erosion load, credited from management of the bacteria TMDL, will provide a head start on the reductions required in the above allocations.

The Mossy Creek sediment TMDL was developed to meet the sediment load of the area-adjusted TMDL reference watershed – Upper Opequon Creek. The TMDL was developed to take into account all sediment sources in the watershed from both point and nonpoint sources. The sediment loads were averaged over a 15-year period to take into account both wet and dry periods in the hydrologic cycle, and the model inputs took into consideration seasonal variations and critical conditions related to sediment loading. An explicit 10% margin of safety was added into the final TMDL load calculation.

1.4. Reasonable Assurance of Implementation

1.4.1. Follow-Up Monitoring

The Department of Environmental Quality (VADEQ) will continue monitoring Mossy Creek (1BMSS001.35, 1BMSS003.01) and Long Glade Run (1BLGC000.96) in accordance with its ambient and biological monitoring programs to evaluate reductions in fecal bacteria counts and improvements in the benthic community, and also the effectiveness of TMDL implementation in attainment of water quality standards.

1.4.2. Regulatory Framework

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria and benthic impairments on Mossy Creek and Long Glade Run. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

1.4.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

1.5. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In May of 2002, members of the Virginia Tech TMDL development group traveled to Rockingham County to become acquainted with the watershed. During that trip, the Virginia Tech personnel spoke with various stakeholders. In addition, Virginia Tech personnel, along with personnel from the Headwaters Soil and Water Conservation District (SWCD) and the Natural Resource Conservation Service (NRCS), visited watershed residents and contacted others via telephone to acquire their input. Two public meetings were held. The first public meeting was organized on June 3, 2003, at the North River Elementary School, to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers in the watershed, fecal production estimates and to discuss the hydrologic calibration. The draft TMDL report was discussed at the final public meeting held on March 2, 2004 at the North River Elementary School.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

Mossy Creek is listed as impaired on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to water quality violations of both the bacteria standard and the General Standard (listed as a benthic impairment).

The Virginia Department of Environmental Quality (VADEQ) has delineated the impairments on Mossy Creek on a stream length of 9.65 miles. The impaired stream segment begins at the Mossy Creek headwaters and continues downstream to its confluence with the North River. Mossy Creek is targeted for TMDL development and completion by 2010.

Long Glade Run is listed as impaired on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to water quality violations of the bacteria standard. The Virginia Department of

Environmental Quality (VADEQ) has delineated the impairment on Long Glade Run on a stream length of 10.74 miles. The impaired stream segment begins at the Long Glade Run headwaters and continues downstream to its confluence with the North River. Long Glade Run is targeted for TMDL development and completion by 2004.

2.1.3. Watershed Location and Description

2.1.3a. Mossy Creek

A part of the Shenandoah River basin, the Mossy Creek watershed (Watershed ID VAV-B19R) is located in Rockingham and Augusta Counties, Virginia, loosely bounded by Route 42 to the east (Figure 2.1). It lies north of Staunton and southwest of Harrisonburg. The watershed is 10,077 acres in size. Mossy Creek is mainly an agricultural watershed (about 72%) and is characterized by a rolling valley with the Blue Ridge Mountains to the east and the Appalachian Mountains to the west. The majority of the remaining 28% of the watershed area is divided between forest and rural developments. Mossy Creek flows north and discharges into the North River (USGS Hydrologic Unit Code 02070005), which is a tributary of the South Fork of the Shenandoah River, which flows into the Potomac River; the Potomac River discharges into the Chesapeake Bay. Mossy Creek is a spring-fed premier trout stream.

2.1.3b. Long Glade Run

A part of the Shenandoah River basin, the Long Glade Run watershed (Watershed ID VAV-B24R) is located in Rockingham and Augusta Counties, Virginia, loosely bounded by Route 42 to the west, where it shares a boundary with the Mossy Creek watershed (Figure 2.1). The Long Glade Run watershed is 11,781 acres in size. Long Glade Run is mainly an agricultural watershed (about 75%) and is characterized by a rolling valley with the Blue Ridge Mountains to the east and the Appalachian Mountains to the west. The remaining 25% of the watershed area is primarily forest (22%), with a small area devoted to rural developments (3%). Long Glade Run flows north and discharges into the North

River (USGS Hydrologic Unit Code 02070005), which is a tributary of the South Fork of the Shenandoah River, which flows into the Potomac River; the Potomac River discharges into the Chesapeake Bay.

2.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with fecal coliform counts are potential sources of pathogenic organisms. For contact recreational activities such as boating and swimming, health risks increase with increasing fecal coliform counts. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state fecal coliform standard for contact recreational uses. As discussed in Section 2.2.2, Virginia has adopted an *Escherichia coli* (*E. coli*) water quality standard. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

Pollution from both point and nonpoint sources can also lead to a violation of the general standard for water quality (Section 2.2.3). This violation is assessed on the basis of measurements of the benthic macro-invertebrate community in the stream, with pollution impacts referred to as a benthic impairment. Water bodies having a benthic impairment are not fully supportive of the aquatic life designated use for Virginia's waters.

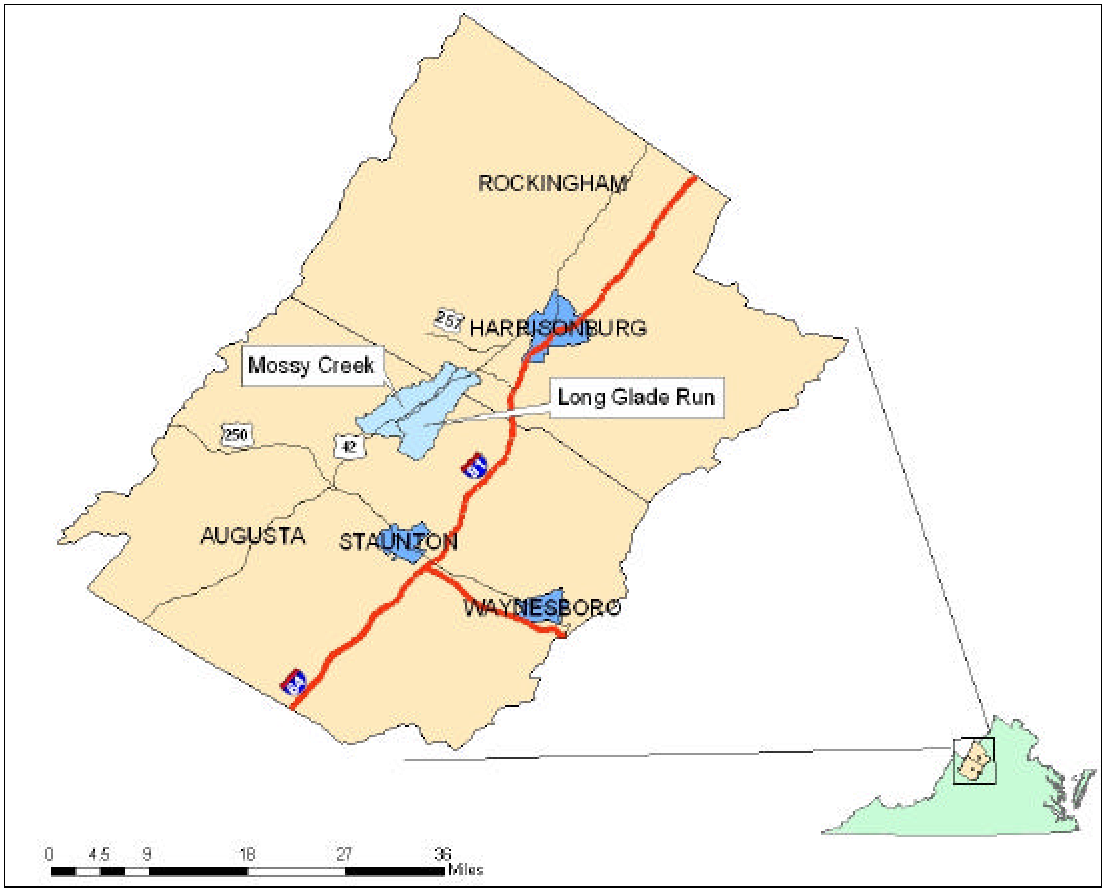

Figure 2.1. Location of Mossy Creek and Long Glade Run watersheds.

2.2. Designated Uses and Applicable Water Quality Standards

2.2.1. Designation of Uses (9 VAC 25-260-10)

> "A. All state waters are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)." SWCB, 2002.

Mossy Creek and Long Glade Run do not support the recreational (swimming) designated use due to violations of the bacteria criteria. Additionally, Mossy Creek does not support the aquatic life designated use due to violations of the general (benthic) criteria.

2.2.2. Bacteria Standard (9 VAC 25-260-170)

EPA has recommended that all States adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than there is with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia. Additionally, prior to June 30, 2008, the interim fecal coliform standard must be applied at any sampling station that has fewer than 12 samples of *E. coli*.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards (as published in the Virginia Register Volume 18, Issue 20) the following criteria shall apply to protect primary contact recreational uses (VADEQ, 2000):

Interim Fecal Coliform Standard:

> Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.

Escherichia coli **Standard**:

> *E. coli* bacteria concentrations for freshwater shall not exceed a geometric mean of 126 counts per 100 mL for two or more samples taken during any calendar month and shall not exceed an instantaneous single sample maximum of 235 cfu/100mL.

During any assessment period, if more than 10% of a station's samples exceed the applicable standard, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the station into compliance with the water quality standard. The original impairment to Mossy Creek and Long Glade Run was based on exceedences of an earlier fecal coliform standard that included a numeric single sample maximum limit of 1000 cfu/100 mL. The bacteria TMDL for these impaired segments will be developed to meet the *E. coli* standard. As recommended by VADEQ, the modeling will be conducted with fecal coliform inputs, and then a translator equation will be used to convert the output to *E. coli*.

2.2.3. General Standard (9 VAC 25-260-20)

The general standard for a water body in Virginia states:

> "A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." SWCB, 2003.

The first paragraph of this standard describes the designated uses for a water body in Virginia. Mossy Creek is violating the general standard for aquatic life use, and thus has a general standard (benthic) impairment.

The Department of Environmental Quality runs the Biological Monitoring Program in Virginia. Evaluations of monitoring data from the program focus on the benthic (bottom-dwelling) macro (large enough to see with the naked eye) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment is supporting the aquatic life use. Changes in water quality generally result in changes in the types and numbers of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions.

This is due to their relative immobility and their variable resistance to the diverse contaminants that can be introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Qualitative and semi-quantitative biological monitoring has been conducted by VADEQ since the early 1970's. The USEPA Rapid Bioassessment Protocol II (RBP II) was employed beginning in the fall of 1990 to utilize standardized and repeatable methodology. For any single sample, the RBP II produces water quality ratings of “non-impaired,” “slightly impaired,” “moderately impaired,” and “severely impaired.” In Virginia, benthic samples are generally taken and analyzed twice a year, in the spring and in the fall.

The RBP II procedure evaluates the benthic macro-invertebrate community by comparing ambient monitoring network stations to reference sites. A reference site is one that has been determined to be representative of a natural, unimpaired water body. The RBP II evaluation also accounts for the natural variation noted in streams in different ecoregions (regions that share characteristics such as meteorological factors, elevation, plant and animal speciation, landscape position, and soils). One additional product of the RBP II evaluation is a habitat assessment. This assessment provides information on the comparability of each stream station to the reference site.

Determination of the degree of support for the aquatic life use is based on conventional water column pollutants (DO, pH, temperature), sediment and nutrient screening value analyses, biological monitoring data, and the best professional judgment of the regional biologist, relying mostly on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with an overall rating of “moderately impaired” or “severely impaired” is placed on the state’s 303(d) list of impaired streams (VADEQ, 2002).

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

3.1.1. Mossy Creek

The Mossy Creek Watershed was subdivided into 8 sub-watersheds for fecal coliform modeling purposes, as discussed in Section 5.2.1. Several unnamed tributaries feed into Mossy Creek. The main branch of Mossy Creek runs for 9.65 miles from the headwaters until it enters the North River. Mossy Creek is perennial and has a trapezoidal channel cross-section. From May 1998 through December 2002, measured discharge ranged from 9 cubic feet per second (cfs) to 87 cfs, with a mean value of 21.2 cfs. Aquifers in this watershed are overlain by limestone, with interbedded limestone, dolomite, and calcareous shale (Soil Survey of Augusta County, Virginia, 1977; Sherwood, 1999). The presence of numerous solution cavities with intensive agricultural use results in a high potential for groundwater pollution (VWCB, 1985).

There are four major springs in the Mossy Creek watershed: Mount Solon Spring, Blue Hole, Cress Pond, and Kyle's Mill Series (Figure 3.1). In addition to the Mossy Creek TMDL study, BSE has been involved in a study entitled "Mossy Creek and Long Glade Run Watershed Monitoring Project." The Virginia Department of Conservation and Recreation (DCR) funds this project. As part of the Mossy and Long Glade Creek Watershed Monitoring Project, flows from the springs that contribute to Mossy Creek were estimated based on local knowledge and field reconnaissance. The approximate flow rates from these springs are shown in Table 3.1. For reference, the approximate flow rate at the BSE downstream monitoring station (Station QMA in Figure 3.1) ranges between 14 and 25 cfs (an estimation based on the rating curve for Mossy Creek). This indicates that spring flows have the potential to constitute approximately 80% of the Mossy Creek flow.

Table 3.1. Discharge Rates of Springs in Mossy Creek.

Spring	Approximate discharge rate (cfs)
Mount Solon Spring	3-7
Blue Hole	1-3
Cress Pond	5-7
Kyle's Mill Series	2-3

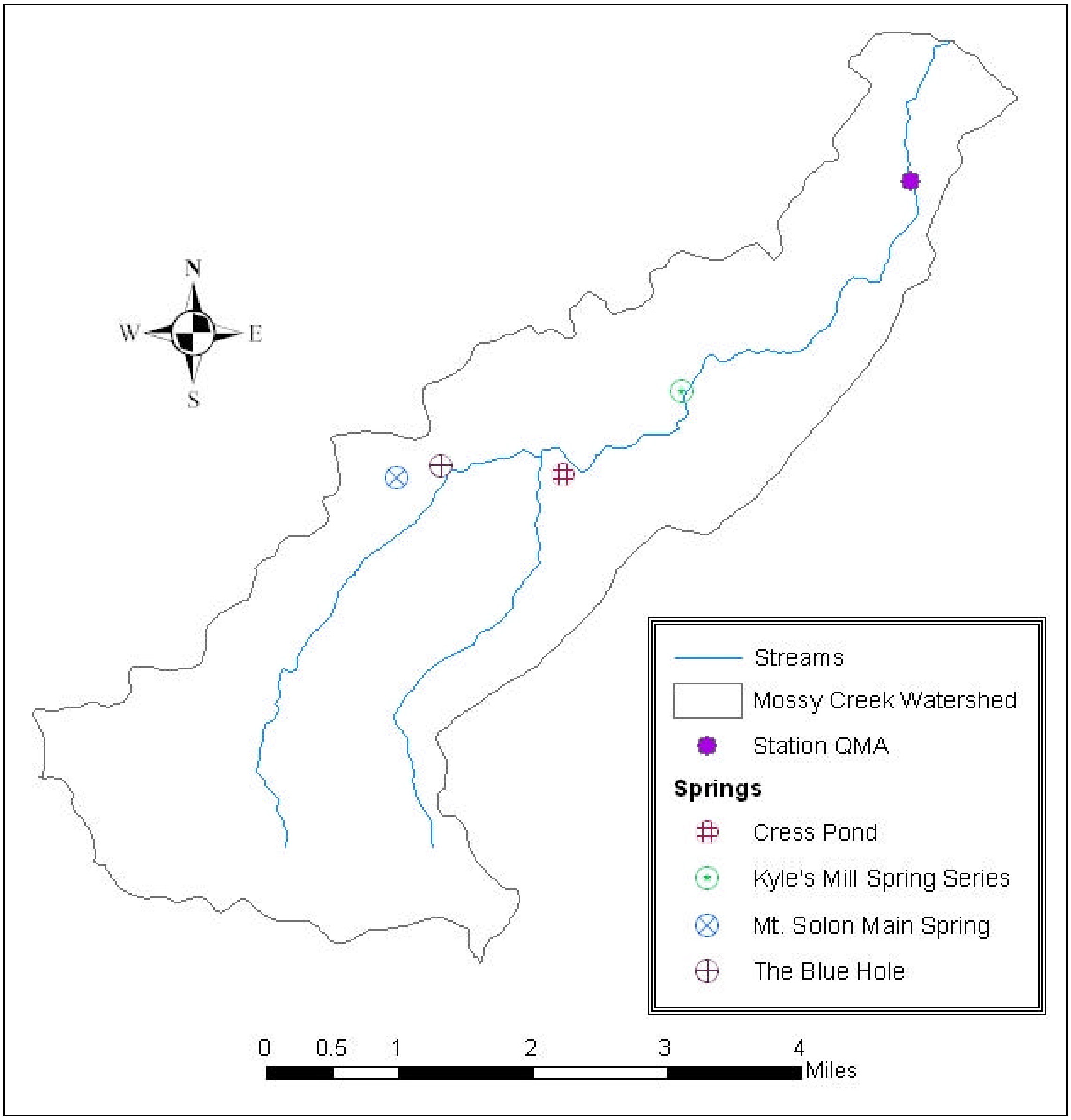

Figure 3.1. Location of Major Springs in the Mossy Creek Watershed.

As an adjunct to the Mossy and Long Glade Creek Watershed Monitoring Project, a dye tracer study was conducted in 2002 with the assistance of staff and resources from the Virginia Department of Conservation and Recreation's Karst Program. The objective of the tracer study was to better understand the area's karst system and related hydrology. Dye was injected at locations thought to be connected to the springs as shown in Table 3.2. A network of very sensitive presence/absence dye traps was placed at each of the major springs in the watershed. Additionally, an automated sampler was set up at the Mount Solon spring.

Table 3.2. Dye injections.

Date	Dye	Injection location
9/18/02	1lb. Fluorescein	North River opposite Stokesville Store
10/2/02	1lb. RWT	North River just downstream of the ford
11/20/02	1lb. Eosine	Freemason Run at Castle Hill, upstream of sink

Both the 10/2/02 injecton and the 11/20/02 injection were recovered by the traps at Mount Solon Spring, indicating that both North River and Freemason Run are connected to Mount Solon Spring. The first 9/18/02 injection at the Stokesville Store was not recovered. This may have been due to dilution, absorption of fluorescein by organic matter, flow to a different spring, or flow to storage in the upstream portion of the Castle Hill doline aquifer.

3.1.2. Long Glade Run

The Long Glade Run Watershed was subdivided into 9 sub-watersheds for fecal coliform modeling purposes. Several unnamed tributaries feed into Long Glade Run. The main branch of Long Glade Run runs for 10.70 miles from the headwaters until it enters the North River. Long Glade Run is perennial and has a trapezoidal channel cross-section. From June 1998 through December 2002, measured discharge ranged from 0 to 62 cfs, with a mean value of 1.94 cfs. Aquifers in this watershed are overlain by limestone, with interbedded limestone, dolomite, and calcareous shale (Soil Survey of Augusta County, Virginia, 1977; Sherwood, 1999). The presence of numerous solution cavities with intensive agricultural use results in a high potential for groundwater pollution (VWCB, 1985).

3.2. Ecoregion

The Mossy Creek and Long Glade Run watersheds are located in the Central Appalachian Ridges and Valleys Level III Ecoregion. It is located primarily in the Northern Limestone/Dolomite Valleys Level IV Ecoregion. The Central Appalachian Ridges and Valleys Ecoregion is characterized by its generation from a variety of geological materials. The Level III Ecoregion has numerous springs and caves. The ridges tend to be forested, while limestone valleys are composed of rich agricultural land (USEPA, 2002). The Northern Limestone/Dolomite Valleys Level IV ecoregion has fertile land and is primarily agricultural. Steeper areas have scattered forests composed mainly of oak trees. Streams tend to flow year-round and have gentle slopes (Woods et al., 1999).

3.3. Soils and Geology

The predominant soil group found in Mossy Creek and Long Glade Run watersheds is Frederick-Christian-Rock outcrop associated soils, characterized by deep, well-drained clay loam to clay. Long Glade has small areas of Chilhowie-Edom associations, characterized by moderately deep to deep dominantly clayey subsoils, while Mossy Creek has small areas of Frederick-Bolton-Christian association, characterized by deep to moderately deep clay loam with some gravel (Soil Survey of Augusta County, Virginia, 1977; Sherwood, 1999). These three general soil map units are found on gently sloping to steep topography with medium to rapid surface runoff (SCS, 1982).

3.4. Climate

The climate of the watershed is characterized based on the meteorological observations made by the Biological Systems Engineering rainfall monitoring station in the Long Glade Run watershed. Other sources of climatological data for the watersheds included: Dale Enterprise (Virginia), Lynchburg Airport (Virginia), and Elkins Airport (West Virginia). The long-term record available at the nearby Dale Enterprise station shows average annual precipitation to be 35.26 in., with 58% of the precipitation occurring during the cropping season (May-October) (SERCC, 2002). Average annual snowfall at Dale Enterprise is 24.8 in., with the highest snowfall occurring during January (SERCC, 2002). Average annual daily temperature is 53.4°F. The highest average daily temperature of 73.7°F occurs in July while the lowest average daily temperature of 32.5°F occurs in January (SERCC, 2002).

3.5. Land Use

Pasture is the main land use category in Mossy Creek and Long Glade Run watersheds, comprising 58% and 60%, respectively, of the total watershed area. Cropland accounts for about 14% of the watershed area for Mossy Creek and 15% for Long Glade Run. Forest acreage accounts for about 25% of the total area for Mossy Creek and 22% for Long Glade Run. Residential and urban developments cover 4% of the total area for Mossy Creek and 3% of Long Glade Run.

3.6. Stream Flow Data

Daily flow rates for Mossy Creek were available from the Biological Systems Engineering monitoring station located in Rockingham County, just upstream from where state road 747 crosses the creek. Monitoring at this station began in May 1998 and ended in December 2002. Daily flow rates for Long Glade Run were available from the Biological Systems Engineering monitoring station located on Route 42 in Rockingham County, at the border with Augusta

County. Monitoring at this station began in June 1998 and ended in December 2002.

3.7. Water Quality Data

The Virginia DEQ (VADEQ) monitored Mossy Creek chemical and bacterial water quality from July 1992 through March 2003. Samples were taken monthly between July 1993 and July 2001 and bimonthly between July 2001 and March 2003. Data on biological communities were collected by VADEQ semi-annually from April 1994 through October 2001. The Virginia Tech Department of Biological Systems Engineering also monitored Mossy Creek chemical and bacterial water quality on a bimonthly basis from February 1998 through December 2002 as a supplement to the VADEQ data. In conjunction with water quality monitoring, Biological Systems Engineering also conducted daily stream flow monitoring from May 1998 through December 2002. Virginia DEQ monitored Long Glade Run chemical and bacterial water quality in the watershed on a non-routine basis from August 1996 through March 2003. Biological Systems Engineering monitored chemical and biological quality between February 1998 and December 2001 and conducted daily stream flow monitoring for Long Glade Run from June 1998 through December 2002. Stream flow data and bacterial water quality data were both available for the period of May 1998 through December 2002 for the Mossy Creek watershed and from June 1998 through December 2003 for the Long Glade Run watershed.

3.7.1. Historic Data – Fecal Coliform

3.7.1.a. Mossy Creek

The Virginia Department of Conservation and Recreation has assessed the Mossy Creek watershed as having a high potential for nonpoint source pollution from agricultural sources. Of the 104 water quality samples collected by VADEQ from July 1992 to March 2003 at the outlet of the watershed (Station ID No. 1BMSS001.35) (Figure 3.2), 51% exceeded the single sample maximum fecal coliform standard of 1,000 cfu/100 mL. Consequently, Mossy Creek was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 1996 305(b) report and was included in the 1996 303(d) list (USEPA, 1996a, b). Of the sixty-six water quality samples collected by Biological Systems Engineering between February 1998 and December 2002, 47% exceeded the single sample maximum fecal coliform standard of 1000 cfu/100 mL.

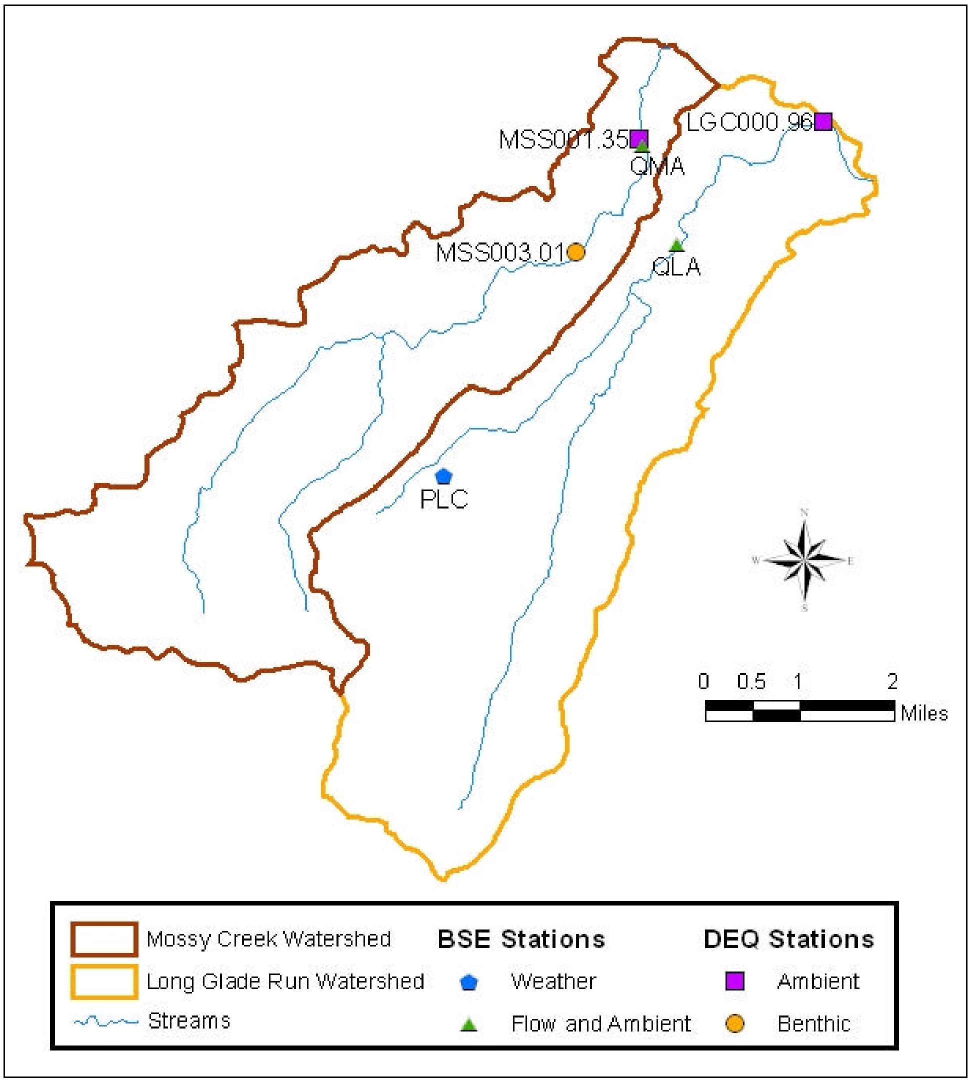

Figure 3.2. Location of sampling stations in the Mossy Creek and Long Glade Run watersheds.

In addition to fecal coliform, the water quality samples taken at station 1BMSS001.35 were analyzed for nitrate, total nitrogen, and total phosphorus.

The 25 samples taken February 2000 to March 2003 were also analyzed for *E. coli*. Time series data of fecal coliform concentration over the July 1992 through March 2003 period are shown in Figure 3.3. In addition to the samples shown in Figure 3.3, two samples were taken by BSE in August and September 2000 with values of 50,000 and 160,000 cfu/100 mL, respectively. One hundred sixty thousand cfu/100 mL is the cap on the BSE data. Time series data of *E. coli* concentration from February 2000 to March 2003 are shown in Figure 3.4.

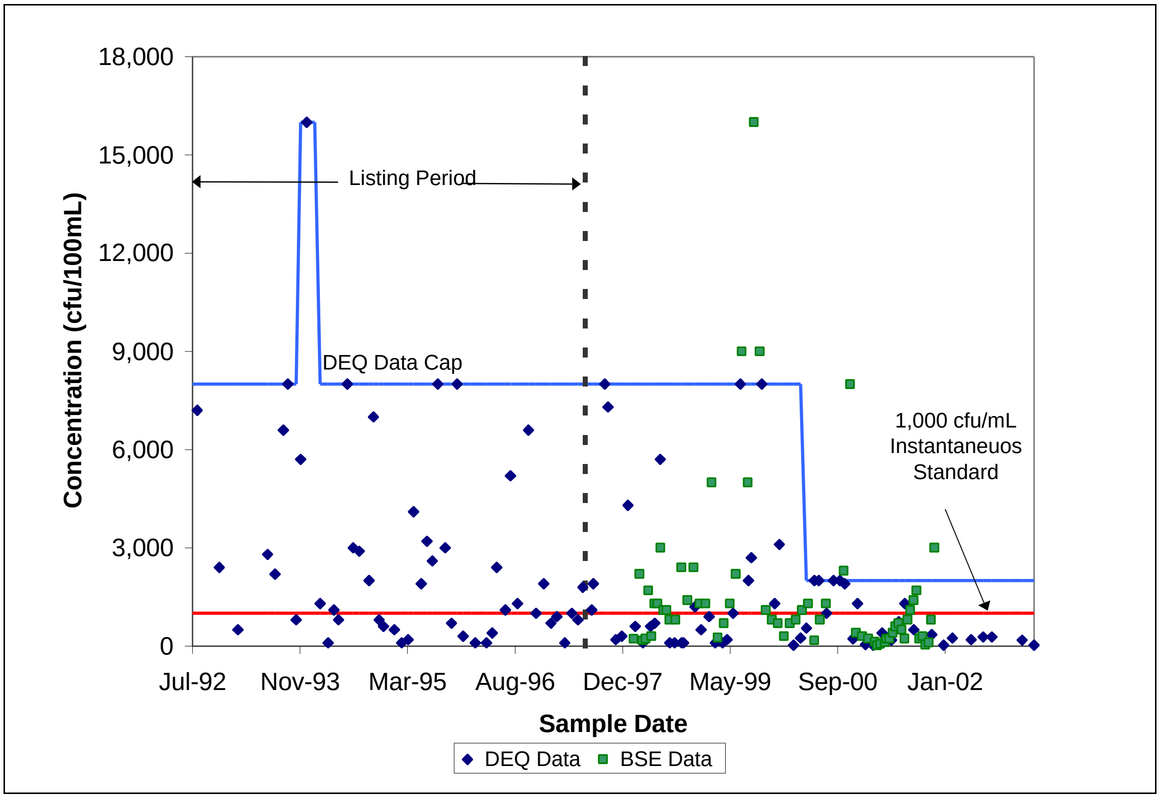

Figure 3.3. Time series of fecal coliform concentration in Mossy Creek.

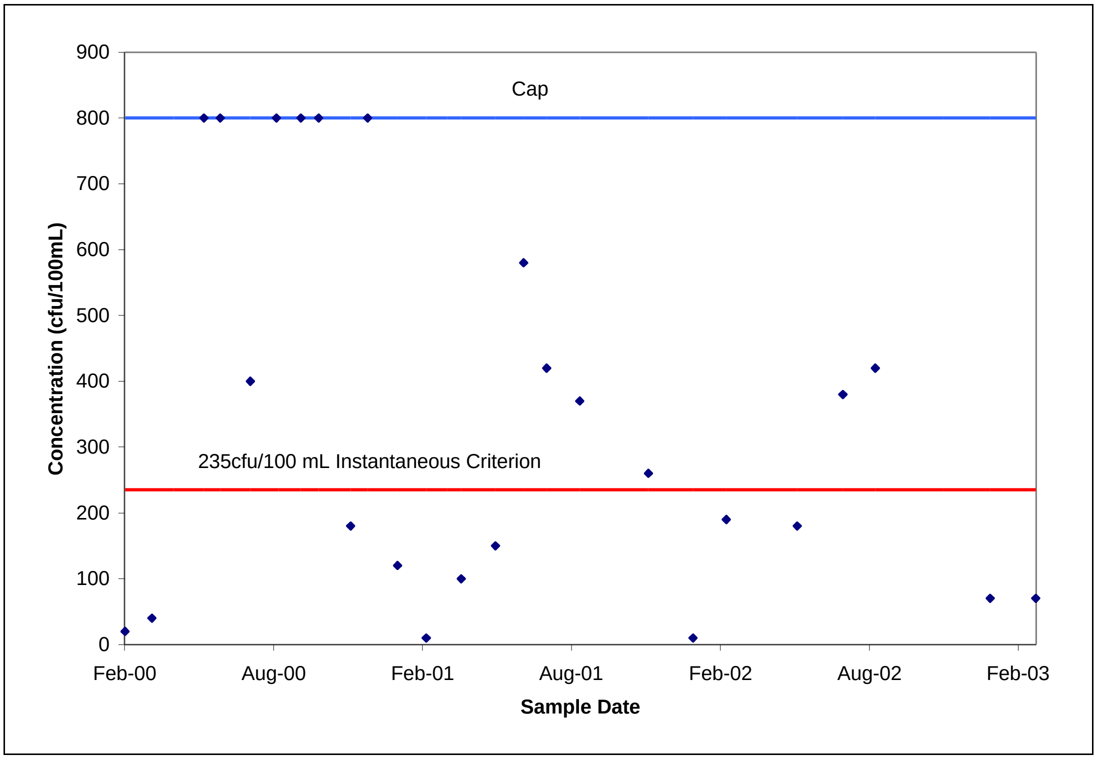

Figure 3.4. Time series of *E. coli* concentration in Mossy Creek.

The Membrane Filter Method (MFM) was used for the analysis of fecal coliform in water samples for Mossy Creek. The samples analyzed with this method had caps of either 8,000 cfu/100 mL or 16,000 cfu/100mL (Figure 3.3). Similarly, the *E. coli* samples had a maximum detection limit of 800 cfu/100 mL (Figure 3.4). Violations of the bacteria water quality standard were observed throughout the reporting period.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values (Figure 3.5). Mean monthly fecal coliform concentration was determined as the average of seven to ten values for each month; the number of values varied according to the available number of samples for each month in the 1992 to 2003 period of record.

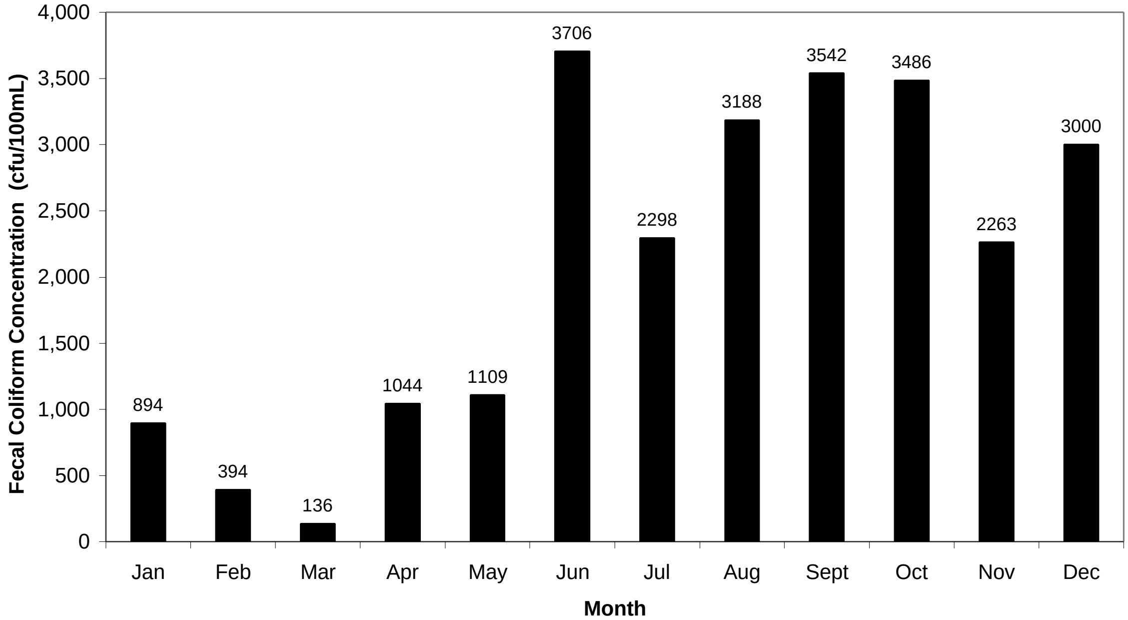

Figure 3.5. Impact of seasonality on fecal coliform concentrations in Mossy Creek.

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the summer and fall months and lower concentrations typically occurring during the winter and spring months. During summer (June – August), the average fecal coliform concentration was 3,064 cfu/100mL compared with 763 cfu/100mL during spring (March – May). Again, it should be noted that due to the cap imposed on the fecal coliform count (8,000 or 16,000 cfu/100 mL), the actual counts could be much higher when fecal coliform levels are equal to these maximum levels, increasing the average shown in Figure 3.5.

The relationship between stream flow rates and DEQ-monitored fecal coliform concentrations is shown in Figure 3.6. The stream flow rate and fecal coliform concentration data in Figure 3.6 are for the period from May 1998 through September 2002, when both data sets were available.

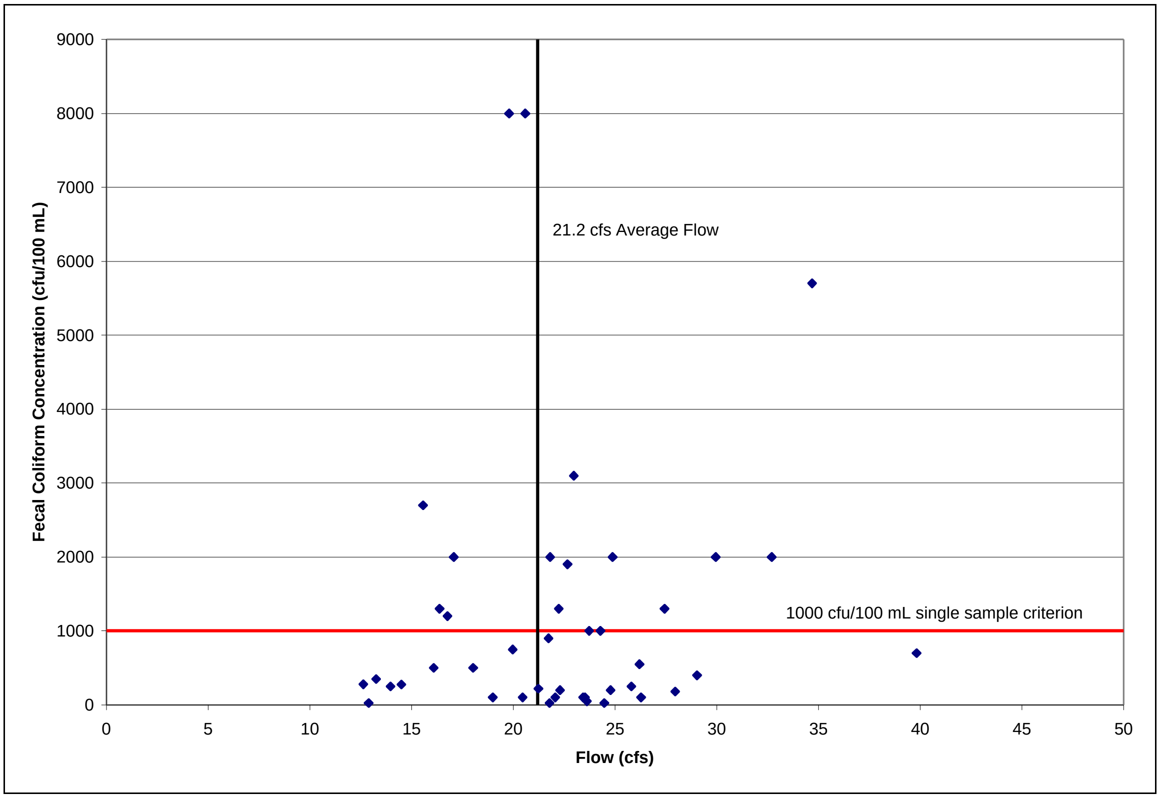

Figure 3.6. Relationship between stream flow and fecal coliform concentration in Mossy Creek from May 1998 through September 2002.

Based on daily flow measurements made from May 1998 through December 2002, mean stream flow in Mossy Creek was 21.2 cfs. Fifteen of the 43 fecal coliform samples (34.9%) violated the 1000 cfu/100 mL single sample criterion during this time period, which is shorter than the total period due to the lack of flow data recorded before 1998 and after 2002. Thirty-eight percent of fecal coliform samples violated the instantaneous criterion of 1,000 cfu/100 mL (Figure 3.6) when flows were lower than the mean value of 21.2 cfs during this period. When flows exceeded the mean flow (21.2 cfs), 33% of the samples violated the instantaneous standard. Most (63%) of the measurements were made when flow values were greater than the mean value for the period. The similar violation rate under high and low flow conditions implies that both direct deposit and land deposit loads are contributing to the fecal coliform impairment.

As mentioned previously (Section 3.1.1), there are spring inputs to the Mossy Creek watershed, some of which are influenced by the flow in the nearby North River watershed. In conjunction with the Mossy Creek and Long Glade Run Watershed Monitoring Project, water quality samples were taken at four springs in the watershed. The results from the sample analyses are shown in Table 3.3. The geometric means of these samples were used in modeling as described in Section 5.5.4

Table 3.3. Observed Fecal Coliform Concentrations in Spring Flows to Mossy Creek.

	Mt. Solon Spring	**Blue Hole Spring**	**Kyle's Mill Spring**	**Cress Pond**
Date	Fecal Coliform, cfu/100 mL or MPN/100 mL			
8/16/2002	10	120	<10	--
9/18/2002	<20	20	--	20
10/2/2002	40	--	--	110
11/21/2002	130	300	40	230
3/12/2003	80	20	<20	--
4/30/2003	70	110	<20	--
5/20/2003	230	800	<20	--
Geometric Mean	54	104	20[a]	80

[a]because of the low values for Kyle's Mill Spring, the concentration typically assigned to groundwater, 20 cfu/100 mL, was used to represent the typical concentration.

3.7.1.b. Long Glade Run

The Virginia Department of Conservation and Recreation has assessed this watershed as having a high potential for nonpoint source pollution from agricultural sources. Of the 29 water quality samples collected by VADEQ from September 1996 to March 2003 at the outlet of the watershed (Station ID No. 1BLGC000.96) (Figure 3.2), 24% exceeded the single sample maximum fecal coliform standard of 1,000 cfu/100 mL. Of the 64 samples collected by Biological Systems Engineering between February 1998 and December 2001, 55% exceeded the single sample maximum fecal coliform standard of 1,000 cfu/100 mL. Consequently, this segment of Long Glade Run was assessed as not supporting the Clean Water Act's Swimming Use Support Goal for the 2002 305(b) report and was included in the 2002 303(d) list (USEPA, 2002a, b).

Virginia DEQ personnel monitored pollutant concentrations at the Long Glade Run watershed outlet over six and a half years (1996-2003) (VADEQ, 1997). From September 1996 through March 2003, samples were not taken on a regular or routine basis.

In addition to fecal coliform, the water quality samples taken at station 1BLGC000.96 were analyzed for nitrate, total nitrogen, and total phosphorus. Only three samples of *E. coli* were available for Long Glade Run. Time series data of fecal coliform concentration over the September 1996 through March 2003 period are shown in Figure 3.7. In addition to the data points in Figure 3.7, two samples, taken in July and December 2001, had concentrations that reached the 160,000 cfu/100 mL cap on the BSE data. The Membrane Filter Method (MFM) was used for the analysis of fecal coliform in water samples. The samples analyzed for Long Glade Run have a maximum detection limit of 8,000 cfu/100 mL. Violations of the fecal coliform water quality standard were observed throughout the reporting period.

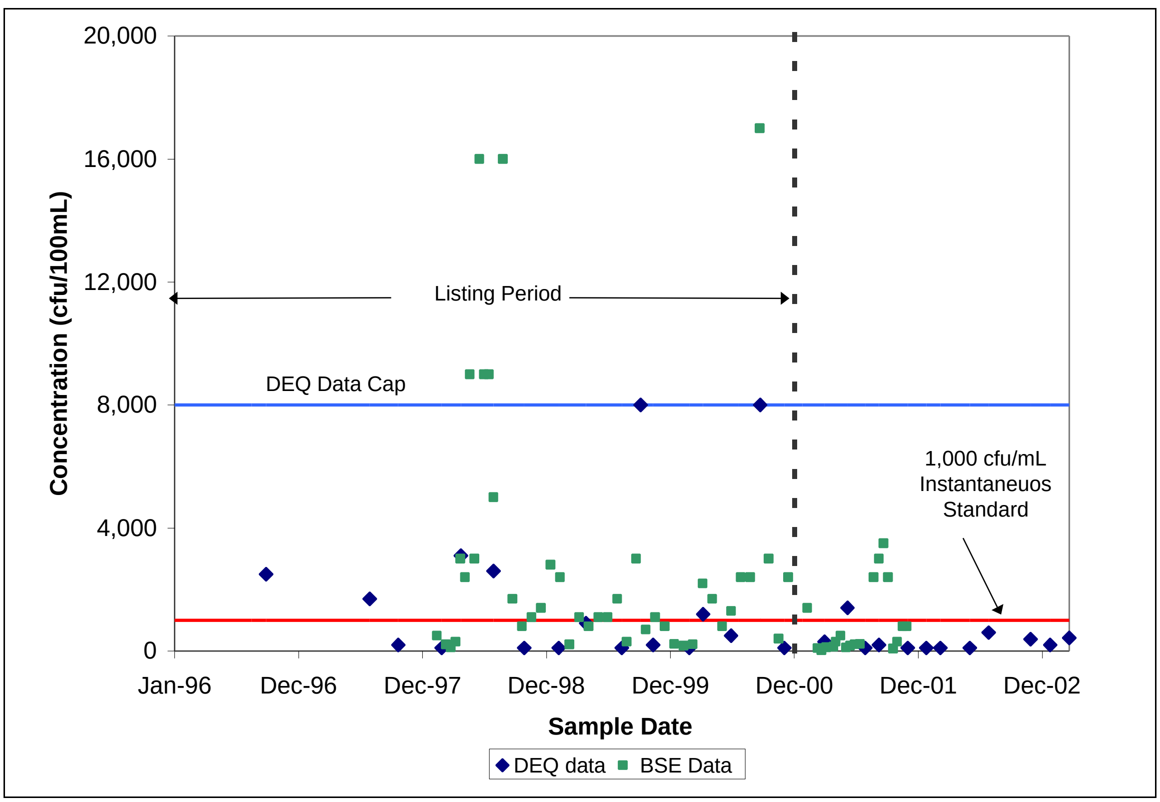

Figure 3.7. Time series of fecal coliform concentration in Long Glade Run.

Seasonality of fecal coliform concentration in the streams was evaluated by plotting the mean monthly fecal coliform concentration values (Figure 3.8). Mean monthly fecal coliform concentration was determined as the average of one to four values for each month; the number of values varied according to the available number of samples for each month in the 1996 to 2003 period of record.

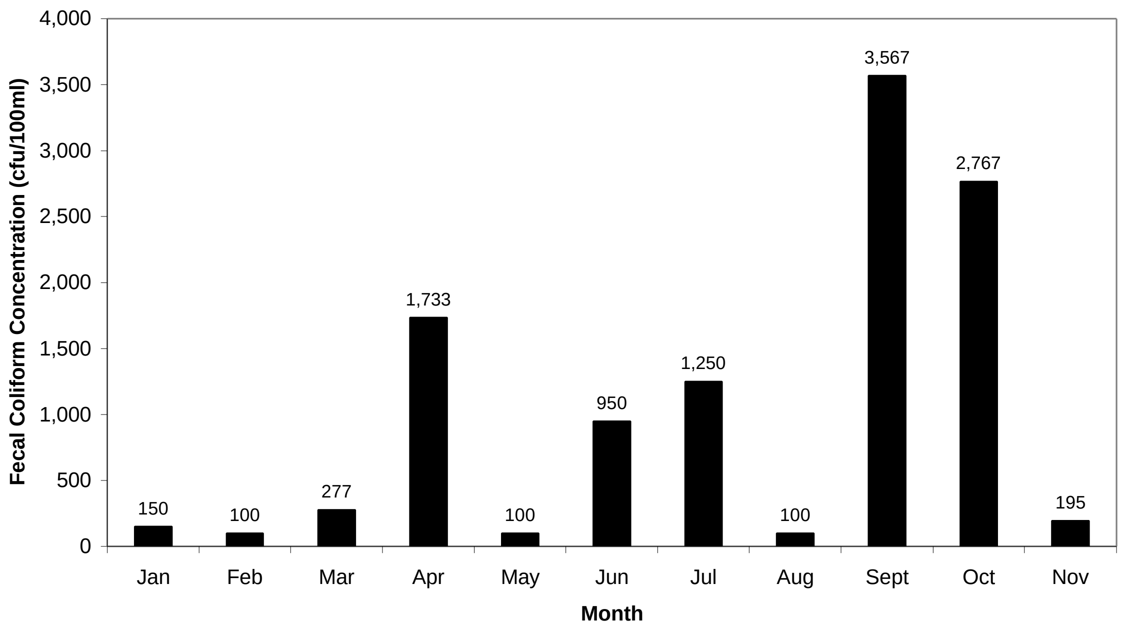

Figure 3.8. Impact of seasonality on fecal coliform concentrations for Long Glade Run.

The data indicate seasonal variability with higher in-stream fecal coliform concentrations occurring during the fall months and lower concentrations typically occurring during the winter months. During fall (September – November), the average fecal coliform concentration was 2,176 cfu/100mL compared with 83 cfu/100mL during winter (December – February). Again, it should be noted that due to the cap imposed on the fecal coliform count (8,000), where fecal coliform levels are equal to the maximum level, the actual counts could be much higher, increasing the average shown in Figure 3.7.

The relationship between stream flow rates and fecal coliform concentrations is shown in Figure 3.9. The stream flow rate and fecal coliform concentration data in Figure 3.9 are for the period from July 1998 through November 2002, when both data sets were available.

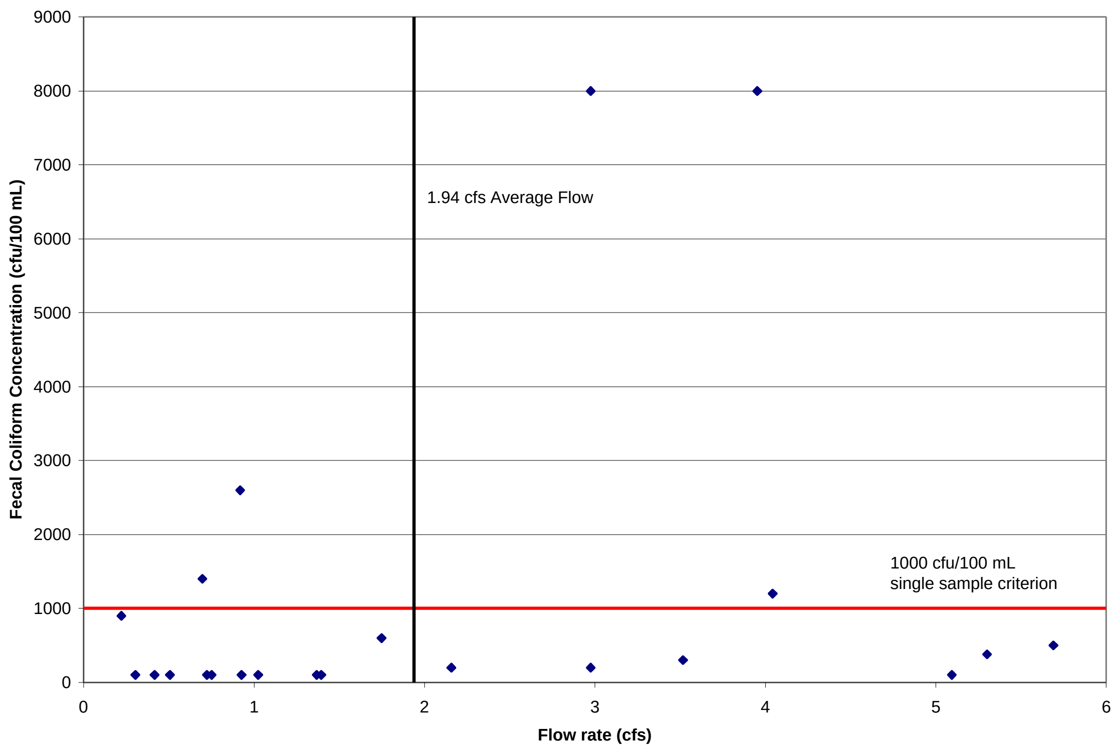

Figure 3.9. Relationship between stream flow and fecal coliform concentration in Long Glade Run from July 1998 through November 2002.

Based on daily flow measurements made from June 1998 through December 2002, mean stream flow in Long Glade Run was 1.94 cfs. Five of the 22 fecal coliform samples (23%) violated the instantaneous criterion during this time period, which is shorter than the total period of record due to the lack of flow data recorded before 1998 and after 2002. Fifteen percent of fecal coliform samples violated the instantaneous criterion of 1,000 cfu/100 mL (Figure 3.9) during this period when flows were lower than the mean value of 1.94 cfs. When flows exceeded the mean flow (1.94 cfs), 33% of the samples violated the instantaneous standard. Most (59%) of the measurements were made when flow values were lower than the mean value for the time period. Higher fecal coliform concentrations under high flow conditions (Figure 3.9) suggest that fecal coliform bacteria transported from the land via overland flow are a significant contributor to the impairment on Long Glade Run.

3.7.2. Historic Data – Benthic Macroinvertebrates

Biological communities have been monitored at MSS003.01 (Figure 3.2) annually or semi-annually from Spring 1994 through the Fall of 2000 and once in the Spring of 2003. The same 9.65 mile Mossy Creek stream segment listed for a bacteria impairment was also placed on the 303(d) list in 1998 for a benthic impairment by the plaintiffs in Virginia's consent decree. VADEQ's 2002 Impaired Waters Fact Sheet states that "biological monitoring indicated Full Use Support in 1998, 2000, and 2002". In each of these assessment periods, the overall assessment was "slightly impaired", which is interpreted as a full use support. A non-supporting use status is reserved for moderate and severe impairments. While the overall ratings for each assessment period was only "slightly impaired", there were individual "moderately impaired" ratings on specific dates. A check of individual sample ratings during each of the respective assessment periods showed 4/6, 4/8, and 3/8 "moderately impaired" ratings, and again for the 2004 assessment period, 2/5 "moderately impaired" ratings. In each of the assessment periods at least two of the "moderate" ratings were given to consecutive samples, except during the 2002 assessment period. For this reason, Mossy Creek watershed was retained on the 303(d) list and a TMDL is required for this moderate to slight impairment.

The Rapid Bioassessment Protocol II (RBP II) is the official protocol used to assess compliance with the general standard in Virginia. The RBP II procedure evaluates the benthic macroinvertebrate community by comparing individual network biomonitoring stations with reference biomonitoring stations on reference streams. Reference biomonitoring stations have been identified by regional biologists that are both representative of regional physiographic and ecological conditions and have a healthy, unimpaired benthic community. Strait

Creek, located in Highland County, Virginia, has been used as the biological reference stream for Mossy Creek. Of the thirteen assessments performed on Mossy Creek since April 1994, seven have received a rating of “moderately” impaired, as shown in Table 3.4.

Table 3.4. RBP II Scores for Mossy Creek (MSS003.01)

Sample Date	4/25/94	10/20/94	5/16/95	10/10/95	10/24/96	5/8/97	10/14/97	10/14/98	5/26/99	10/13/99	5/3/00	10/13/00	3/10/03
Samp_ID		44	271	425	696	803	981	1289	1400	2737	2797	2858	3001
a. RBP II Metric Values													
Taxa Richness	13	13	15	17	15	11	15	13	13	16	18	13	14
MFBI	4.64	5.34	4.64	5.03	5.18	4.94	5.12	4.69	4.76	4.96	4.76	4.67	5.38
SC/CF	0.62	0.31	0.85	0.72	0.09	0.03	0.51	0.65	1.50	0.88	0.55	0.54	0.17
EPT/Chi Abund	24.25	3.21	6.31	4.67	5.67	3.60	4.25	33.50	3.29	7.00	4.88	3.78	3.30
% Dominant	42.37	33.58	24.58	18.63	36.73	24.30	34.29	34.00	32.20	28.44	20.00	23.48	42.20
Dominant Species	Ephemere	Hydropsy	Hydropsy	Hydropsy	Hydropsy	Ephemerel	Hydropsyc	Hydropsyc	Ephemerel	Heptagenii	Hydropsychi	Hydropsyc	Hydropsych
EPT Index	6	4	7	7	8	6	6	5	5	6	10	6	6
Comm. Loss Index	1.54	0.62	0.93	0.47	0.33	1.00	0.47	0.62	0.77	0.75	0.50	0.77	0.79
SH/Tot	0.02	0.00	0.05	0.01	0.03	0.05	0.01	0.02	0.01	0.03	0.04	0.00	0.01
b. Reference Metric Values													
Station_ID	STC004.2	STC004.2	STC004.2	STC004.2	STC004.2	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27
Reference Sample Date		10/11/94	5/11/95	10/26/95	10/17/96	5/21/97	9/30/97	10/28/98	5/17/99	10/13/99	5/4/00	10/13/00	6/2/03
Reference Sample_ID		36	270	447	704	816	995	1294	1435	2755	2813	2874	3000
Taxa Richness	31	20	25	19	16	19	17	19	18	21	20	19	20
MFBI	3.48	3.47	3.05	2.89	3.78	3.37	3.86	3.18	3.79	3.64	4.15	3.61	4.14
SC/CF	1.67	0.59	1.53	0.38	0.20	0.26	0.25	0.23	1.70	2.21	0.78	1.56	1.63
EPT/Chi Abund	5.10	55.00	18.60	74.00	14.29	19.67	63.00	36.50	4.87	29.00	3.80	20.00	1.68
% Dominant	19.11	25.28	16.80	21.30	32.80	21.43	28.30	21.84	20.66	25.23	16.00	25.23	32.26
EPT Index	17	9	12	10	8	13	9	13	11	10	12	12	12
Comm. Loss Index	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SH/Tot	0.12	0.02	0.22	0.14	0.05	0.08	0.05	0.28	0.17	0.15	0.11	0.05	0.11
Reference Biological Score	48	46	48	46	44	46	46	46	46	46	48	46	44
c. RBP II Metric Ratios													
Taxa Richness	41.9	65.0	60.0	89.5	93.8	57.9	88.2	68.4	72.2	76.2	90.0	68.4	70.0
MFBI	75.0	65.0	65.6	57.4	73.0	68.2	75.4	67.9	79.5	73.3	87.2	77.3	77.0
SC/CF	37.2	53.0	55.6	187.7	43.5	9.7	204.7	281.1	88.2	39.7	70.5	34.8	10.3
EPT/Chi Abund	475.5	5.8	33.9	6.3	39.7	18.3	6.7	91.8	67.6	24.1	128.5	18.9	197.0
% Dominant	42.4	33.6	24.6	18.6	36.7	24.3	34.3	34.0	32.2	28.4	20.0	23.5	42.2
EPT Index	35.3	44.4	58.3	70.0	100.0	46.2	66.7	38.5	45.5	60.0	83.3	50.0	50.0
Comm. Loss Index	1.54	0.62	0.93	0.47	0.33	1.00	0.47	0.62	0.77	0.75	0.50	0.77	0.79
SH/Tot	14.0	0.0	22.7	7.1	63.8	59.5	18.9	7.3	5.1	18.0	35.7	0.0	8.1
d. RBP II Metric Scores													
Taxa Richness	2	4	2	6	6	2	6	4	4	4	6	4	4
MFBI	4	2	2	2	4	2	4	2	4	4	6	4	4
SC/CF	4	6	6	6	4	0	6	6	6	4	6	2	0
EPT/Chi Abund	6	0	2	0	2	0	0	6	4	0	6	0	6
% Dominant	0	2	4	6	2	4	2	2	2	4	4	4	0
EPT Index	0	0	0	0	6	0	0	0	0	0	4	0	0
Comm. Loss Index	2	4	4	6	6	4	6	4	4	4	4	4	4
SH/Tot	0	0	2	0	6	6	0	0	0	0	4	0	0
Total RBP II Score	18	18	22	26	36	18	24	24	24	20	40	18	18
% of Reference	37.50	39.13	45.83	56.52	81.82	39.13	52.17	52.17	52.17	43.48	83.33	39.13	40.91
RBP II Assessment	**Moderate**	**Moderate**	**Moderate**	**Slight**	**Slight**	**Moderate**	**Slight**	**Slight**	**Slight**	**Moderate**	**No Impact**	**Moderate**	**Moderate**

[1] RBP II Impairment Ratings: "Severe" 0-17; "Moderate" 21-50; "Slight" 54-79; "No Impact" 83-100.

The Macroinvertebrate Aggregated Index for Streams (MAIS) is a secondary index whose metrics are also calculated by VADEQ, but it is only used as a supplemental indicator of stream quality. The MAIS metrics were developed using data from the Central Appalachian Ridge and Valley ecoregion, and as such, are appropriate for use with Mossy Creek watershed. Individual MAIS metrics are rated against a fixed scale rather than against those of a reference watershed, as in the RBP II index. The various metrics, some which duplicate those in the RBP II, along with their scores and final ratings are given for each sample in Table 3.5.

Table 3.5. MAIS Assessment Results for Mossy Creek

a. MAIS Metric Values

Sample Date	4/25/94	10/20/94	5/16/95	10/10/95	10/24/96	5/8/97	10/14/97	10/14/98	5/26/99	10/13/99	5/3/00	10/13/00	3/10/03	**Best Score (2)**
% 5 Dominant	86.44	83.94	77.97	65.69	80.61	91.59	80.95	84.00	92.37	78.90	81.60	84.85	85.32	<79.13
MFBI	4.6	5.3	4.6	5.0	5.2	4.9	5.1	4.7	4.8	5.0	4.8	4.7	5.38	<4.22
% Haptobenthos	84.7	68.6	82.2	69.6	52.0	65.4	69.5	85.0	67.8	75.2	66.4	76.5	71.56	>83.26
EPT Index	6	4	7	7	8	6	6	5	5	6	10	6	6	>7
# Mayfly Taxa	4	3	3	4	5	3	4	3	4	3	4	3	3	>3
% Mayfly Abundance	57.6	22.6	38.1	15.7	30.6	38.3	27.6	29.0	55.9	33.0	40.0	21.2	15.60	>17.52
Simpson's Diversity Index	0.76	0.82	0.86	0.90	0.81	0.82	0.82	0.82	0.81	0.83	0.88	0.84	0.77	>0.823
# Intolerant Taxa	8	9	10	12	11	7	10	10	8	9	13	8	8	>9
% Scraper Abundance	15.25	14.60	23.73	22.55	4.08	0.93	20.95	31.00	17.80	33.03	12.80	24.24	7.34	>10.7
b. MAIS Scores														
% 5 Dominant	1	1	2	2	1	1	1	1	1	2	1	1	1	2
MFBI	1	1	1	1	1	1	1	1	1	1	1	1	1	2
% Haptobenthos	2	1	1	1	1	1	1	2	1	1	1	1	1	2
EPT Index	1	1	1	1	2	1	1	1	1	1	2	1	1	2
# Mayfly Taxa	2	1	1	2	2	1	2	1	2	1	2	1	1	2
% Mayfly Abundance	2	2	2	1	2	2	2	2	2	2	2	2	1	2
Simpson's Diversity Index	1	1	2	2	1	1	1	1	1	1	2	2	1	2
# Intolerant Taxa	1	1	2	2	2	1	2	2	1	1	2	1	1	2
% Scraper Abundance	2	2	2	2	1	1	2	2	2	2	2	2	1	2
Total MAIS Score	13	11	14	14	13	10	13	13	12	12	15	12	9	**18**
MAIS Assessment	**Good**	**Poor**	**Good**	**Good**	**Good**	**Poor**	**Good**	**Good**	**Poor**	**Poor**	**Good**	**Poor**	**Poor**	**Best**

[1] MAIS Ratings: "Very Poor" 0-6; "Poor" 7-12; "Good" 13-16; "Very Good" 17-18.

A qualitative analysis of various habitat parameters was conducted in conjunction with each biological sampling event. Each of the 10 parameters listed in Table 3.6 had a maximum score of 20 indicating the most desirable condition, and a score of 0 indicating the poorest habitat conditions. The best possible overall score for a single evaluation is 200.

Table 3.6. Habitat Evaluation Scores for Mossy Creek

	Habitat Evaluation Dates											
Habitat Metrics	5/16/95	10/10/95	10/24/96	5/8/97	10/14/97	10/14/98	5/26/99	10/13/99	5/3/00	10/31/00	3/10/2003	Average
Channel Alterations	16	12	16	16	14	19	17	17	18	16	12	15.7
Bank Stability	16	14	14	16	16	18	16	17	20	17	18	16.5
Bank Vegetation	18	16	14	14	16	20	20	20	20	20	16	17.6
Embeddedness	12	10	12	10	10	17	20	16	19	14	12	13.8
Flow Regime	20	20	20	20	20	19	20	20	19	19	20	19.7
Presence of Riffles	12	12	12	14	10	17	18	17	18	18	14	14.7
Riparian Vegetation Zone	12	10	10	20	10	20	20	20	19	19	16	16.0
Sediment	12	12	14	14	10	18	18	17	19	19	12	15.0
Bottom Substrate	12	12	12	12	12	18	18	17	19	17	16	15.0
Velocity of Flow	12	10	12	12	12	15	15	16	19	18	16	14.3
Total Habitat Score	142	128	136	148	130	181	182	177	190	177	152	158.5

[1] EPA Habitat Evaluation Ratings

(Bank Stability, Bank Vegetation, Riparian Vegetation Zone Width): Poor 0-5; "Marginal" 6-10"; "Sub-optimal" 11-15; "Optimal" 16-20

(All Other Metrics): "Poor" 0-5; "Marginal" 6-10"; "Sub-optimal" 11-15; "Optimal" 16-20

Additional habitat data was available from citizen monitoring data from 1998-1999, as shown in Table 3.7. This data indicates an overall good "Stream Quality", but also indicated increasing streambank erosion (SB erosion) and increasing percentages of fines on the stream bottom.

Table 3.7. Mossy Creek Citizen Monitoring Data

DEQ Station ID	**1BMSS-1-SOS**		**Citizen's Monitoring Data**		
Date	**4/19/98**	**7/17/98**	**10/24/98**	**1/16/99**	**5/29/99**
Stream Quality Score	20	16	22	26	20
Stream Quality Rating	Good	Fair	Good	Excellent	Good
% algae cover			60	0	
SB erosion	20	0	10	50	
% mud	0	2	0	10	
%sand	0	0	10	10	
%gravel	10	10	20	20	
%cobbles	40	40	30	50	
%boulders	50	50	40	10	
Flow rate	high	normal	low	normal	low

Virginia DEQ, with assistance from USEPA Region 3, is in the middle of a process to upgrade its biomonitoring and biological assessment methods to those currently recommended in the mid-Atlantic region. As part of this effort, a study has been performed to assist the agency to move from a paired-reference site/stream approach to a regional reference condition approach, and has led to the development of a proposed stream condition index (SCI) for Virginia's non-coastal areas (Tetra Tech, 2002). This multimetric index is based on 8 biomonitoring metrics, with a scoring range of 0-100, that are different than those used in the RBP II. The maximum score of 100 represents the best benthic community sites. Current proposed threshold criteria would define "unimpaired" sites as those with an SCI > 61.9 (the 10th percentile of all scores from 62 reference sites in Virginia), and "impaired" sites as those with an SCI < 56.3 (the 5th percentile). The average SCI score for Mossy Creek is 57.99 (Table 3.8), which falls in the grey boundary zone between "impaired" and "unimpaired" sites, and indicates that Mossy Creek has a relatively minor impairment, consistent with the RBP II test's borderline moderate to slightly impaired ratings (The “slightly impaired” category in the RPB II was never intended to indicate an impairment). The average SCI score for Strait Creek is consistent with that of “unimpaired” sites.

Table 3.8. Stream Condition Index

Station ID	Stream Name	No. of Samples	Stream Condition Index		
			Minimum	Maximum	Average
Impaired Stream Site					
MSS003.01	Mossy Creek	13	48.61	67.75	57.99
Biological Reference Stream Site					
STC004.27	Strait Creek	17	65.81	87.18	77.58

CHAPTER 4: SOURCE ASSESSMENT OF FECAL COLIFORM

Fecal coliform sources in the Mossy Creek and Long Glade Run watershed were assessed using information from the following sources: VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Department of Agricultural and Consumer Services (VDACS), Virginia Cooperative Extension (VCE), NRCS, public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Point sources and potential nonpoint sources of fecal coliform are described in detail in the following sections and summarized in Table 4.2 for Mossy Creek and Table 4.16 for Long Glade Run.

Point sources of fecal coliform bacteria in the Mossy Creek and Long Glade Run watersheds include all municipal and industrial plants that treat human waste, as well as private residences that fall under general permits. Virginia issues Virginia Pollutant Discharge Elimination System (VPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain a fecal coliform concentration of 200 cfu/100 mL or less in their effluent. There were only 4 general permits between the two watersheds, as detailed in Table 4.1. In allocation scenarios for bacteria, the entire allowable point source discharge concentration of 200 cfu/100 mL was used.

Table 4.1. General Permits discharging into Mossy Creek and Long Glade Run.

Permit Number	Facility Name	City	Discharge Type	Sub-Watershed	Design Flow (gpd)	Permitted FC Conc. (cfu/100 mL)	FC Load (cfu/year)	Permitted TSS Conc. (mg/L)	TSS Load (t/year)
VAG401481	Homeowner, SR 699	Bridgewater	Single Family Home (SFH)	LG-1	1000	200	$2.76*10^9$	30	0.0415
VAG401746	Homeowner, SR 646/699	Bridgewater	SFH	LG-7	1000	200	$2.76*10^9$	30	0.0415
VAG401919	Homeowner, SR 699	Bridgewater	SFH	LG-1	1000	200	$2.76*10^9$	30	0.0415
VAG401083	Homeowner, SR 747	Mount Solon	Private (PRVT)	MC-7	1000	200	$2.76*10^9$	30	0.0415

.

4.1. Mossy Creek Sources

A synopsis of the fecal coliform sources characterized and accounted for in the Mossy Creek watershed, along with average fecal coliform production rates are shown in Table 4.2. In addition to these sources, the bacteria contributions from springs as described in Section 3.7.1a were accounted for in the Mossy Creek watershed. A detailed discussion of how the spring contributions were modeled is presented in section 5.3.3.

Table 4.2. Potential fecal coliform sources and daily fecal coliform production by source in Mossy Creek watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	1,330	1,950[a]
Dairy cattle		
Milk and dry cows	805	20,200[b]
Heifers [c]	610	9,200[d]
Beef cattle	2,932	20,000
Pets	402	450[e]
Poultry		
Chicken Broilers	398,600	136[f]
Turkey Toms	21,000	93[f]
Turkey Hens	71,000	93[f]
Turkey Breeders	23,500	93[f]
Sheep		
Ewes	120	12,000[f]
Lambs	240	
Goats	23	
Horses	6	420[f]
Deer	472	350
Raccoons	197	50
Muskrats	118	25[g]
Beavers	18	0.2
Wild Turkeys	98	93[f]
Ducks	93	800
Geese	108	2,400

[a] Source: Geldreich *et al*. (1978)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e] Source: Weiskel *et al*. (1996)
[f] Source: ASAE (1998)
[g] Source: Yagow (2001)

4.1.1. Humans and Pets

The Mossy Creek watershed has an estimated population of 1330 people (402 households at an average of 3.31 people per household; actual people per household varies by sub-watershed). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

4.1.1.a. Failing Septic Systems

Septic system failure can be evidenced by the rise of effluent to the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. There were no sewered areas in the Mossy Creek watershed. Unsewered households were located using E-911 digital data, (see Glossary) (Rockingham Co. Planning Dept., 2001; Augusta Co. Planning Dept., 2003). Each unsewered household was classified into one of three age categories (pre-1967, 1967-1987, and post-1987) based on USGS 7.5-min. topographic maps which were initially created using 1967 photographs and were photo-revised in 1987. Professional judgment was applied in assuming that septic system failure rates for houses in the pre-1967, 1967-1987, and post-1987 age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed located in Rockingham County), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate ranged from 1.11 to 4.66 persons per household (Census Bureau, 2000)) by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 1.11 persons/household was 2.15×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.3.

4.1.1.b. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1967 and 1967-1987 age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, it was estimated that the Mossy Creek watershed had 1 straight pipe located in sub-watershed 6.

4.1.1.c. Pets

Assuming one pet per household, there are 402 pets in Mossy Creek watershed. A dog produces fecal coliform at a rate of 0.45×10^9 cfu/day (Weiskel et al., 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table 4.3. Pet waste is generated in the farmstead, rural residential, and urban residential land use types. Surface runoff can transport bacteria in pet waste from residential areas to the stream.

Table 4.3. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population in Mossy Creek watershed.

Sub-watershed	Unsewered houses in each age category (no.)			Failing septic systems (no.)	Pet population[a]
	Pre-1967	1967-1987	Post-1987		
MC-01	9	22	19	9	50
MC-02	6	4	6	3	16
MC-03	13	6	28	7	47
MC-04	8	2	12	4	22
MC-05	5	1	13	3	19
MC-06	31	9	71	16	112
MC-07	33	8	32	16	73
MC-08	32	8	23	15	63
Total	137	60	204	73	402

[a] Assumed an average of one pet per household.

4.1.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animal waste deposited on pastures or applied to crop, pasture, and hay land.

4.1.2.a. Distribution of Dairy and Beef Cattle in the Mossy Creek Watershed

There are 6 dairy farms in the watershed, based on reconnaissance and information from VDACS. From communication with local dairy farmers, it was determined that there are 695 milk cows, 110 dry cows, and 610 heifers in the watershed (Table 4.2). The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farms. Table 4.4 shows the number of dairy operations for each sub-watershed.

Table 4.4. Distribution of dairy cattle, dairy operations and beef cattle among Mossy Creek sub-watersheds.

Sub-watershed	Dairy cattle	No. of dairy operations	Beef cattle
MC-01	90	1	213
MC-02	242	1	225
MC-03	0	0	295
MC-04	167	1	162
MC-05	0	0	271
MC-06	585	1	737
MC-07	120	1	166
MC-08	211	1	863
Total	1,415	6	2,932

Beef cattle in the watershed included cow/calf and feeder operations. There was one permitted beef CAFO in the watershed (Table J.1). The exact number of beef operations in the watershed is not known; the beef cattle population (2,932 cattle) in the watershed was estimated based on communication with Dr. Dan Eversole, the beef specialist at Virginia Tech (August 14, 2002), regarding stocking rates for various pasture categories. The stocking rates were particular to the classification of pasture areas. In the following discussion and throughout this report, pasture 1 represents the VADCR land use classification “improved pasture.” Pasture 2 corresponds to “unimproved pasture” and Pasture 3 to “overgrazed pasture.” The following procedure was used to estimate beef population by sub-watershed (Table 4.4).

1. Based on communication with Dr. Dan Eversole, it was assumed that the ratio of the stocking rates for pasture types 1, 2, and 3 was 4:2:1. This means that pasture 2 had a stocking rate twice that of pasture 3, and that pasture 1 had a stocking rate twice that of pasture 2.

2. The stocking rates of the three pasture types were determined as a combination of information on the carrying capacity of the pastures and data from VADCR. Beef cattle stocking rates for pastures 1, 2, and 3 were 0.71, 0.36, and 0.18 beef cattle/acre, respectively.

3. The number of beef cattle in each pasture category was calculated by multiplying the pasture acreage by the stocking rate for that pasture category.

Beef and dairy cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (e.g., milk cow versus heifer). Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Based on discussions with NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream.

a) Cows are confined according to the schedule given in Table 4.5.

b) When the milk cows are not confined or in loafing lots, they spend 100% of the time on pasture. All other dairy (dry cows and heifers) and beef cattle are also on pastures when not in confinement or loafing lots. Dairy cows only occupy pasture 1.

c) Pasture 1 (improved pasture/hayland) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).

d) Cows on pastures that are contiguous to streams (980 acres for all pasture categories, Table 4.6) have stream access.

e) Cows with stream access spend varying amounts of time in the stream during different seasons (Table 4.5). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.

f) Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the manure is deposited on pastures.

Table 4.5. Time spent by cattle in confinement and in the stream.

Month	Time spent in confinement (%)		Time spent in the stream (hours/day)[a]
	Milk cows	Dry cows, heifers, and beef cattle	
January	75%	40%	0.50
February	75%	40%	0.50
March	40%	0%	0.75
April	30%	0%	1.00
May	30%	0%	1.50
June	30%	0%	3.50
July	30%	0%	3.50
August	30%	0%	3.50
September	30%	0%	1.50
October	30%	0%	1.00
November	40%	0%	0.75
December	75%	40%	0.50

[a] Time spent in and around the stream by cows that have stream access.

Table 4.6. Pasture acreages contiguous to stream.

Sub-watershed	Pasture 1		Pasture 2	
	Acres	%[a]	Acres	%[a]
MC-01	7.9	2%	0	0%
MC-02	37.1	9%	0	0%
MC-03	69.5	13%	0	0%
MC-04	0.0	0%	0	0%

MC-05	64.0	13%	0	0%
MC-06	316.3	24%	42.4	26%
MC-07	19.1	7%	0	0%
MC-08	424.5	27%	0	0%
Total	938.3	18%	42.4	9%

[a] Percent of area contiguous to stream to the total pasture area of that type in that sub-watershed.

A sample calculation for determining the distribution of cattle to different land use types and to the stream in sub-watershed MC-8 is shown in Appendix B. The resulting numbers of cattle in each land use type as well as in the stream for all sub-watersheds are given in Table 4.7 for dairy cattle and in Table 4.8 for beef cattle.

Table 4.7. Distribution of the dairy cattle[a] population.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Streams[b]	Loafing[c]
January	809.25	566.01	29.53	0.00	0.61	9.60
February	809.25	566.01	29.53	0.00	0.61	9.60
March	278.00	1056.15	56.11	0.00	1.71	23.04
April	208.50	1117.37	59.85	0.00	2.40	26.88
May	208.50	1116.23	59.78	0.00	3.61	26.88
June	208.50	1111.68	59.52	0.00	8.41	26.88
July	208.50	1111.68	59.52	0.00	8.41	26.88
August	208.50	1111.68	59.52	0.00	8.41	26.88
September	208.50	1116.23	59.78	0.00	3.61	26.88
October	208.50	1117.37	59.85	0.00	2.40	26.88
November	278.00	1056.15	56.11	0.00	1.71	23.04
December	809.25	566.01	29.53	0.00	0.61	9.60

[a] Includes milk cows, dry cows, and heifers.
[b] Number of dairy cattle defecating in stream.
[c] Milk cows in loafing lot.

Table 4.8. Distribution of the beef cattle population.

Months	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[a]	Loafing
January	1348.72	1909.08	81.61	0.00	2.17	30.22
February	1583.28	2241.09	95.81	0.00	2.54	35.48
March	0.00	3843.74	164.31	0.00	6.55	60.88
April	0.00	3952.20	168.94	0.00	8.98	62.63
May	0.00	4058.34	173.46	0.00	13.85	64.39
June	0.00	4150.63	177.34	0.00	33.21	66.14
July	0.00	4260.58	182.04	0.00	34.09	67.89
August	0.00	4370.54	186.74	0.00	34.96	69.64
September	0.00	4500.06	192.34	0.00	15.36	71.39

October	0.00	2763.78	118.14	0.00	6.28	43.80
November	0.00	2903.54	124.12	0.00	4.95	45.99
December	1290.08	1826.07	78.06	0.00	2.07	28.91

[a] Number of beef cattle defecating in stream.

4.1.2.b. Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 4.7) and beef cattle (Table 4.8) defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 397,676 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 5.18×10^{11} cfu/day. Part of the fecal coliform deposited in the stream stays suspended while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that suspended fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.1.2.c. Direct Manure Deposition on Pastures

Dairy (Table 4.7) and beef (Table 4.8) cattle that graze on pastures but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Because the confinement schedule of the cattle changes with season, manure and fecal coliform loading on pasture also change with season.

Pasture 1 and pasture 2 have average annual cattle manure loadings of 18,933 and 10,315 lb/ac-year, respectively. The loadings vary because stocking rate varies with pasture type. Fecal coliform loadings from cattle on a daily basis, averaged over the year, are 2.42×10^{10} and 1.27×10^{10} cfu/ac-day for pastures 1 and 2, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

4.1.2.d. Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 lb and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule (Table 4.7) and the number of milk cows (Table 4.2), annual liquid dairy manure production in the watershed is 1.8 million gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 1.18×10^9 cfu/gal. Liquid dairy manure receives priority over other manure types (poultry litter and solid cattle manure) when applied to land. Liquid dairy manure application rates are 6,600 and 3,900 gal/ac-year to cropland and pasture land use categories, respectively, with cropland receiving priority in application. Based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 280 acres (20.4%) of cropland. Because there was more than enough crop area to receive the liquid manure produced in the watershed, no liquid dairy manure was applied to pasture.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay. It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-

November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn, and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye, and surface-applied to cropland under rotational hay. In all months except December and January, liquid manure can be surface-applied to pasture 1. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure is given in Table 4.9. Dry cows and heifers were assumed to produce only solid manure.

Table 4.9. Schedule of cattle and poultry waste application in the Mossy Creek watershed.

Month	Liquid manure applied (%)[a]		Solid manure or poultry litter applied (%)[a]	
	Crops	Pasture	Crops	Pasture
January	0	0	0	0
February	7.1	5	6.7	5
March	35.7	25	33.3	25
April	28.6	20	26.7	20
May	7.1	5	6.7	5
June	0	10	0	5
July	0	0	0	5
August	0	5	0	5
September	0	15	0	10
October	7.1	5	13.3	10
November	14.3	10	13.3	10
December	0	0	0	0

[a] As percent of annual load applied to each land use type.

4.1.2.e. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.10. Solid Manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed (Table 4.4) and their confinement schedules (Table 4.5). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.10).

Table 4.10. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, and fecal coliform concentration in fresh solid manure in individual cattle type.

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)
Dry cow	110	1,400[a]	115.0[b]	176[c]
Heifer	610	640[d]	40.7[a]	226[c]
Beef	2,932	1,000[e]	60.0[b]	333[c]

[a] Source: ASAE (1998)
[b] Source: MWPS (1993)
[c] Based on per capita fecal coliform production per day (Table 4.2) and manure production
[d] Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).
[e] Based on input from local producers

Solid manure is applied at the rate of 12 tons/ac-year to both cropland and pasture, with priority given to cropland. As in the case of liquid manure, solid manure is only applied to cropland during February through May, October, and November. Solid manure can be applied to pasture during the whole year, except December and January. The method of application of solid manure to cropland or pasture is assumed to be identical to the method of application of liquid dairy manure. The application schedule for solid manure is given in Table 4.9. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 33.5 acres (2.4%) of the cropland and 339 acres

(6.4%) of pasture 1. Because the areas of cropland, pasture 1, and pasture 2 were more than adequate to accommodate the solid manure application, solid manure was not applied to pasture 2.

4.1.3. Poultry

The poultry population (Table 4.2) was estimated based on the permitted combined feeding operations (CAFO) located within the watershed and discussions with local producers and nutrient management specialists. A complete listing of poultry CAFOs can be found in Table J.2 in Appendix J.Poultry litter production was estimated from the poultry population after accounting for the time when the houses are not occupied.

Because poultry is raised entirely in confinement, all litter produced is collected and stored prior to land application. The estimated production rate of poultry litter in the Mossy Creek watershed is 1.63×10^{7} lb/year, which corresponds to a fecal coliform production rate of 1.64×10^{16} cfu/year. This fecal coliform produced is subject to die-off in storage and losses due to incorporation prior to being subject to transport via runoff. Poultry litter is applied at the rate of 3 tons/ac-year first to cropland, and then to pastures at the same rate. Poultry litter receives priority after all liquid manure has been applied (i.e., it is applied before solid cattle manure is considered). The method of poultry litter application to cropland and pastures is assumed to be identical to the method of cattle manure application. The application schedule of poultry litter is given in Table 4.9. As with liquid and solid manures, poultry litter is not applied to cropland during June through September. Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, it was estimated that poultry litter was applied to 1,061 acres (77%) of cropland; 1,639 acres (31%) of pasture 1; and 13 acres (2.9%) of Pasture 2.

4.1.4. Sheep and Goats

The sheep and goat populations (Table 4.2) were estimated based on discussions with nutrient management specialists and observations of the watershed. The sheep herd was composed of lambs and ewes. The lamb population was expressed in equivalent sheep numbers. The equivalent sheep population calculated for lambs was based on the assumption that the average weight of a lamb is half of the weight of a sheep. The lamb population for the Mossy Creek watershed was estimated to be 240 animals. The equivalent sheep population for the lambs was 120. A similar approach was used for goats. The equivalent number of sheep for goats was calculated based on the ratio of animal weights. It was assumed that the average weight for a goat and a sheep were 140 lb and 60 lb, respectively (ASAE, 1998). The equivalent number of goats (23) was calculated as the ratio of the goat weight to the sheep weight (140/60) times the number of goats in the watershed (23). The total number of sheep for the Mossy Creek watershed was the sum of the number of ewes (120), equivalent number of lambs (120), and the equivalent number of goats (23), for a total of 263 animals. The sheep were kept on pastures 1 and 2. The relative stocking density for sheep was estimated to be 0.6 for pasture 1 and 0.4 for pasture 2 based on discussions with local producers. The equivalent sheep population for each sub-watershed is shown Table 4.11. Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was added to the loads applied to pastures 1 and 2.

Table 4.11. Sheep and Goat Populations in Mossy Creek Sub-Watersheds.

Sub-watershed	Goat	Ewe	Lamb
MC-01	0	0	0
MC-02	0	0	0
MC-03	0	30	60
MC-04	0	0	0
MC-05	0	0	0
MC-06	20	40	80
MC-07	0	0	0
MC-08	3	50	100
Total	23	120	240

Pasture 1 and pasture 2 have average annual sheep manure loadings of 59 and 179 lb/ac-year, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings from sheep on a daily basis averaged over the year are 3.97×10^{8} cfu/ac-day and 3.11×10^{9} cfu/ac-day for pastures 1 and 2, respectively.

4.1.5. Horses

Horse populations for the Mossy Creek watershed were obtained through observations of the watershed and communication with local producers. The total horse population was estimated to be 6. The distribution of horse population among the sub-watersheds is listed in Table 4.12. Horses are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by horses was added to the loads applied to the three pasture types. Fecal coliform loadings from horses on a daily basis averaged over the year and over pasture areas in the entire watershed are 4.43×10^{5} cfu/ac-day and 3.42×10^{5} for pastures 1 and 2, respectively.

Table 4.12. Horse Populations among Mossy Creek Sub-Watersheds.

Sub-watershed	Horse Population
MC-01	2
MC-02	1
MC-03	0
MC-04	0
MC-05	2
MC-06	0
MC-07	1
MC-08	0
Total	6

4.1.6. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, professional trappers, and watershed residents were used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 4.2) along with preferred habitat and habitat area (Table 4.13).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, considering the habitat area each occupied (Table 4.13). Fecal matter produced by deer that is not directly deposited in streams is distributed among pastures and forest. Raccoons deposit their waste in streams and forests. Muskrats deposit their waste in streams, forest, and cropland.

Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on the area of appropriate habitat in each sub-watershed. For example, the deer population was evenly distributed across the watershed, whereas a 66 ft buffer around streams and impoundments in forest and crop areas determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments and more area in forest and crop land use would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments, and less area in forest and crop land use. Distribution of wildlife among sub-watersheds is given in Table 4.14.

Table 4.13. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Acres of habitat	Population Density (animal/ac-habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	10,072	0.047	0.5%

Raccoon	600 ft buffer around streams and impoundments	2,804	0.07	5%
Muskrat	66 ft buffer around streams and impoundments in forest and cropland	43	2.75	12.5%
Beaver	300 ft buffer streams and impoundments in forest and pasture	1,147	0.015	25%
Geese	300 ft buffer around main streams	1,000	0.078 – off season 0.1092 – peak season	12.5%
Wood Duck	300 ft buffer around main streams	1,000	0.0624 – off season 0.0936 – peak season	12.5%
Wild Turkey	Entire Watershed except urban and farmstead	9,758	0.01	5%

Table 4.14. Distribution of wildlife among sub-watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
MC-01	32	23	14	2	10	9	6
MC-02	36	18	15	2	12	10	8
MC-03	46	16	18	1	11	9	10
MC-04	22	6	0	0	0	0	5
MC-05	49	22	19	2	13	11	10
MC-06	113	50	19	5	28	24	24
MC-07	29	19	0	2	9	8	5
MC-08	145	43	33	4	25	22	30
Total	472	197	88	18	108	93	98

4.1.7. Summary: Contribution from All Sources

Based on the inventory of sources discussed in this chapter, a summary of the contribution by the different nonpoint sources to direct annual fecal coliform loading to the streams is given in Table 4.15. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4.15.

From Table 4.15, it is clear that nonpoint source loadings to the land surface are 260 times larger than direct loadings to the streams (not including commercial sources), with pastures receiving about 96% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors; such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure) and proximity to streams; also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

Table 4.15. Annual fecal coliform loadings to the stream and the various land use categories in the Mossy Creek watershed.

Source	Fecal coliform loading ($x10^{12}$ cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	189	0.4%
Wildlife in stream	12.5	<0.1%
Straight pipes	3.4	<0.1%
Loading to land surfaces		
Cropland	666	1.2%
Pasture 1	48,891	91.3%
Pasture 2	2,622	4.9%
Loafing Lots	852	1.6%
Residential[a]	238	0.4%
Forest	103	0.2%
Total	53,576	

[a] Includes loads received from both High and Low Density Residential and Farmstead due to failed septic systems and pets.

4.2. Long Glade Run Sources

A synopsis of the fecal coliform sources characterized and accounted for in the Long Glade Run watershed, along with average fecal coliform production rates are shown in Table 4.16.

Table 4.16. Potential fecal coliform sources and daily fecal coliform production by source in Long Glade Run watershed.

Potential Source	Population in Watershed	Fecal coliform produced ($\times 10^6$ cfu/head-day)
Humans	971	1,950[a]
Dairy cattle		
Milk and dry cows	749	20,200[b]
Heifers [c]	496	9,200[d]
Beef cattle	2,705	20,000
Pets	349	450[e]
Poultry		
Broilers	370,000	136[f]
Turkey Toms	19,000	93[f]
Turkey Hens	114,400	93[f]
Sheep		
Ewes	112	12,000[f]
Lambs	224	
Goats	157	
Horses	27	420[f]
Deer	420	0.0725

Raccoons	196	50
Muskrats	125	25[g]
Beavers	20	0.2
Wild Turkeys	87	93[f]
Ducks	76	0.0725
Geese	88	0.0725

[a] Source: Geldreich *et al*. (1978)
[b] Based on data presented by Metcalf and Eddy (1979) and ASAE (1998)
[c] Includes calves
[d] Based on weight ratio of heifer to milk cow weights and fecal coliform produced by milk cow
[e] Source: Weiskel *et al*. (1996)
[f] Source: ASAE (1998)
[g] Source: Yagow (2001)

4.2.1. Humans and Pets

The Long Glade Run watershed has an estimated population of 971 people (349 households at an average of 2.78 people per household; actual people per household varies according to sub-watershed). Fecal coliform from humans can be transported to streams from failing septic systems or via straight pipes discharging directly into streams.

4.2.1.b. Failing Septic Systems

Septic system failure can be evidenced by the rise of effluent to the soil surface. Surface runoff can transport the effluent containing fecal coliform to receiving waters. There were no sewered areas in the watershed. Unsewered households were located using E-911 digital data, (see Glossary) (Rockingham Co. Planning Dept., 2001; Augusta Co. Planning Dept., 2003). Each unsewered household was classified into one of three age categories (pre-1967, 1967-1987, and post-1987) based on USGS 7.5-min. topographic maps which were initially created using 1967 photographs and were photo-revised in 1987. Professional judgment was applied in assuming that septic system failure rates for houses in the pre-1967, 1967-1987, and post-1987 age categories were 40, 20, and 3%, respectively (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed located in Rockingham County), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate ranged from 2.74 to 2.81 persons per household (Census Bureau, 2000)) by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 2.74 persons/household was 5.34×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watershed is given in Table 4.17.

4.2.1.c. Straight Pipes

Of the houses located within 150 ft of streams, in the pre-1967 and 1967-1987 age categories, 10%, and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, it was estimated that the watershed had no straight pipes.

4.2.1.d. Pets

Assuming one pet per household, there are 349 pets in Long Glade Run watershed. A dog produces fecal coliform at a rate of 0.45×10^9 cfu/day (Weiskel et al., 1996); this was assumed to be representative of a 'unit pet' – one dog or several cats. The pet population distribution among the sub-watersheds is listed in Table 4.17. Pet waste is generated in the rural residential and urban residential land use types. Surface runoff can transport bacteria in pet waste from residential areas to the stream.

Table 4.17. Estimated number of unsewered houses by age category, number of failing septic systems, and pet population in Long Glade Run watershed.

Sub-watershed	Unsewered houses in each age category (no.)			Failing septic systems (no.)	Pet population[a]
	Pre-1967	1967-1987	Post-1987		
LG-01	16	22	27	12	37
LG-02	8	10	18	6	26
LG-03	9	10	18	6	37
LG-04	9	2	12	4	23
LG-05	1	0	0	0	1
LG-06	28	1	27	12	56
LG-07	23	5	20	11	48
LG-08	14	3	21	7	38
LG-09	26	15	42	15	83
Total	134	68	185	73	349

[a] Assumed an average of one pet per household. Includes pets from sewered households.

4.2.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream by surface runoff from animal waste deposited on pastures or applied to crop and hay land.

4.2.2.a. Distribution of Dairy and Beef Cattle in the Long Glade Run Watershed

There are six dairy farms in the watershed, based on reconnaissance and information from VDACS. From communication with local dairy farmers, it was determined that there are 616 milk cows, 133 dry cows, and 496 heifers in the watershed (Table 4.16). The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farms (Table 4.18). Table 4.18 shows the number of dairy operations for each sub-watershed.

Table 4.18. Distribution of dairy cattle, dairy operations and beef cattle among Long Glade Run sub-watersheds.

Sub-watershed	Dairy cattle	No. of dairy operations	Beef cattle
LG-01	0	0	131
LG-02	0	0	109
LG-03	80	1	158
LG-04	440	1	230

LG-05	0	0	38
LG-06	568	3	596
LG-07	25	0	428
LG-08	0	0	455
LG-09	132	1	560
Total	1,245	6	2,705

The same assumptions were made for the beef cattle in the Long Glade watershed as were made for the beef cattle in the Mossy Creek watershed; please see Section 4.1.2 for a detailed description of the calculations used to obtain the beef numbers in Table 4.18. The stream access information in Table 4.19 was used to calculate the cattle distributions presented in Table 4.20 and Table 4.21 according to the procedure in Appendix B.

Table 4.19. Pasture acreages contiguous to stream.

Sub-watershed	Pasture 1		Pasture 2	
	Acres	%[a]	Acres	%[a]
LG-01	6.1	2%	0.9	2%
LG-02	19.8	8%	0.0	0%
LG-03	46.4	13%	3.1	4%
LG-04	0.0	0%	0.0	0%
LG-05	16.3	18%	0.0	0%
LG-06	104.3	7%	1.1	1%
LG-07	103.3	10%	0.0	0%
LG-08	92.0	9%	12.1	5%
LG-09	0.0	0%	0.0	0%
Total	388.2	6%	17.2	2%

[a] Percent of pasture area with cattle access to stream to the total pasture area of that type in that sub-watershed.

Table 4.20. Distribution of the dairy cattle[a] population.

Month	Confined	Pasture 1	Pasture 2	Stream[b]	Loafing[c]
January	713.60	500.71	19.36	0.13	11.20

February	713.60	500.71	19.36	0.13	11.20
March	246.40	934.72	36.64	0.36	26.88
April	184.80	989.31	39.02	0.51	31.36
May	184.80	989.07	39.00	0.77	31.36
June	184.80	988.10	38.94	1.79	31.36
July	184.80	988.10	38.94	1.79	31.36
August	184.80	988.10	38.94	1.79	31.36
September	184.80	989.07	39.00	0.77	31.36
October	184.80	989.31	39.02	0.51	31.36
November	246.40	934.72	36.64	0.36	26.88
December	713.60	500.71	19.36	0.13	11.20

[a] Includes milk cows, dry cows, and heifers.
[b] Number of dairy cattle defecating in stream.
[c] Milk cows in loafing lot.

Table 4.21. Distribution of the beef cattle population.

Months	Confined	Pasture 1	Pasture 2	Stream[a]	Loafing
January	1244.30	1717.09	107.58	0.66	41.12
February	1460.70	2015.71	126.29	0.77	48.28
March	0.00	3458.45	216.67	1.99	82.84
April	0.00	3557.34	222.85	2.73	85.23
May	0.00	3655.54	228.99	4.21	87.61
June	0.00	3749.67	234.80	10.08	90.00
July	0.00	3849.00	241.02	10.35	92.38
August	0.00	3948.33	247.24	10.62	94.76
September	0.00	4053.43	253.91	4.66	97.15
October	0.00	2487.65	155.84	1.91	59.60
November	0.00	2612.50	163.67	1.50	62.58
December	1244.30	1717.09	107.58	0.66	41.12

[a] Number of beef cattle defecating in stream.

4.2.2.b. Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 4.20) and beef cattle (Table 4.21) defecating in the stream. However, only cattle on pastures contiguous to streams have stream access. Manure loading increases during the warmer months when cattle spend more time in water, compared to the cooler months. Average annual manure loading directly deposited by cattle in the stream for the watershed is 114,026 lb. Daily fecal coliform loading due to cows depositing in the stream, averaged over the year, is 1.59×10^{11} cfu/day. Part of the fecal coliform deposited in the stream stays suspended while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that suspended fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

4.2.2.c. Direct Manure Deposition on Pastures

Based on the assumptions set forth in Section 4.1.2.c, Table 4.20, and Table 4.21, pasture 1 and pasture 2 areas in the Long Glade Run watershed have average annual cattle manure loadings of 14,229 and 6,487 lb/ac-year, respectively. The loadings vary because stocking rate varies with pasture type. Fecal coliform loadings from cattle on a daily basis, averaged over the year, are 1.82×10^{10} and 8.69×10^{9} cfu/ac-day for pastures 1 and 2, respectively.

4.2.2.d. Land Application of Liquid Dairy Manure

Based on the monthly confinement schedule (Table 4.5) and the number of milk cows (Table 4.16), annual liquid dairy manure production in the watershed is 1.6 million gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 1.18×10^{9} cfu/gal. Using the same assumptions set forth in Section 4.1.2.d., based on availability of land and liquid dairy manure, as well as the assumptions regarding application rates and priority of application, it was estimated that liquid dairy manure was applied to 248 acres (15.5%) of cropland. Because there was more than enough crop area to receive the liquid manure produced in the watershed, no liquid dairy manure was applied to pasture.

The same application schedule used for the Mossy Creek watershed applies to the manure application activities in the Long Glade Run watershed.

4.2.2.e. Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 4.22. The amount of solid manure applied in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed (Table 4.18) and their confinement schedules (Table 4.5). Solid manure from dry cows, heifers, and beef cattle contained different fecal coliform concentrations (cfu/lb) (Table 4.22).

Table 4.22. Estimated population of dry cows, heifers, and beef cattle, typical weights, per capita solid manure production, and fecal coliform concentration in fresh solid manure in individual cattle type.

Type of cattle	Population	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure ($\times 10^6$ cfu/lb)
Dry cow	133	1,400[a]	115.0[b]	176[c]
Heifer	496	640[d]	40.7[a]	226[c]
Beef	2,705	1,000[e]	60.0[b]	333[c]

[a] Source: ASAE (1998)
[b] Source: MWPS (1993)
[c] Based on per capita fecal coliform production per day (Table 4.16) and manure production

[d] Based on weighted average weight assuming that 57% of the animals are older than 10 months (900 lb ea.), 28% are 1.5-10 months (400 lb ea.) and the remainder are less than 1.5 months (110 lb ea.) (MWPS, 1993).
[e] Based on input from local producers

Solid manure is applied as described in Section 4.1.2.e. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 210 acres (13.9%) of the cropland and 139 acres (2.2%) of pasture 1. Because the areas of cropland and pasture 1 were more than adequate to accommodate the solid manure application, solid manure was not applied to pasture 2.

4.2.3. Poultry

The poultry population (Table 4.16) was estimated based on the permitted combined feeding operations (CAFO) located within the watershed and discussions with local producers and nutrient management specialists. A complete listing of the permitted CAFOs in the Long Glade Run watershed is shown in Table J.3. Poultry litter production was estimated from the poultry population after accounting for the time when the houses are not occupied.

The estimated production rate of poultry litter in the Long Glade Run watershed is 1.67×10^{7} lb/year, which corresponds to a fecal coliform production rate of 1.58×10^{16} cfu/year. Poultry litter was assumed to be applied in Long Glade Run watershed as in the Mossy Creek watershed (Section 4.1.3). Based on availability of land and poultry litter, as well as the assumptions regarding application rates and priority of application, it was estimated that poultry litter was applied to 975 acres (64.5%) of cropland; 1,544 acres (24%) of pasture 1; and 256 acres (31.8%) of Pasture 2.

4.2.4. Sheep and Goats

The sheep and goat populations (Table 4.16) were estimated based on discussions with DCR nutrient management specialists and observations of the watershed. The sheep herd was composed of lambs and ewes. The lamb population was expressed in equivalent sheep numbers as described in Section 4.1.4. The lamb population for the Long Glade Run watershed was estimated to be 224 animals. The equivalent sheep population for the lambs was 112. The equivalent number of sheep for goats also estimated as described in Section 4.1.4. The equivalent number of goats (366) was calculated as the ratio of the goat weight to the sheep weight (140/60) times the number of goats in the watershed (157). The total number of sheep for the Long Glade Run watershed was the sum of the number of ewes (112), equivalent number of lambs (112), and the equivalent number of goats (366), for a total of 590 animals. The sheep were kept on pastures 1 and 2. The relative stocking density for sheep was estimated to be 0.6 for pasture 1 and 0.4 for pasture 2 based on discussions with local producers. The equivalent sheep population for each sub-watershed is shown in Table 4.23. Sheep and goats are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by sheep and goats was added to the loads applied to pastures 1 and 2.

Table 4.23. Sheep and Goat Populations in Long Glade Run Sub-Watersheds.

Sub-watershed	Goat Population	Ewe Population	Lamb Population
LG-01	0	0	0
LG-02	0	0	0
LG-03	0	10	20
LG-04	0	0	0
LG-05	0	0	0
LG-06	10	0	0

LG-07	49	6	12
LG-08	18	12	24
LG-09	80	84	168
Total	157	112	224

Pasture 1 and pasture 2 have average annual sheep manure loadings of 48 and 255 lb/ac-year, respectively. The loadings vary because stocking density varies with pasture type. Fecal coliform loadings from sheep on a daily basis averaged over the year are 2.39×10^{11} cfu/ac-day and 1.28×10^{12} cfu/ac-day for pastures 1 and 2, respectively.

4.2.5. Horses

Horse populations for the Long Glade Run watershed were obtained through observations of the watershed and communication with local producers. The total horse population was estimated to be 27. The distribution of horse population among the sub-watersheds is listed in Table 4.24. Horses are not usually confined and tend not to wade or defecate in the streams. Therefore, the fecal coliform produced by horses was added to the loads applied to the three pasture types. Fecal coliform loadings from horses on a daily basis averaged over the year and over pasture areas in the entire watershed are 5.71×10^{8} cfu/ac-day and 5.75×10^{8} cfu/ac-day for pastures 1 and 2, respectively.

Table 4.24. Horse Populations among Long Glade Run Sub-Watersheds.

Sub-watershed	Horse Population
LG-01	0
LG-02	4
LG-03	3
LG-04	0
LG-05	0

LG-06	4
LG-07	1
LG-08	3
LG-09	12
Total	27

4.2.6. Wildlife

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, professional trappers, and watershed residents were used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined (Table 4.16) along with preferred habitat and habitat area (Table 4.25).

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, considering the habitat area each occupied (Table 4.25). The assumptions on habitat areas for wildlife in the Long Glade Run watershed were the same as those made for the Mossy Creek watershed (Section 4.1.6). Distribution of wildlife among sub-watersheds is given in Table 4.26.

Table 4.25. Wildlife habitat description and acreage, and percent direct fecal deposition in streams.

Wildlife type	Habitat	Acres of habitat	Population Density (animal/ac-habitat)	Direct fecal deposition in streams (%)

Deer	Entire Watershed	11,866	0.047	0.1%
Raccoon	600 ft buffer around streams and impoundments	3,700	0.07	1%
Muskrat	66 ft buffer around streams and impoundments in forest and cropland	61	2.75	2.5%
Beaver	300 ft buffer streams and impoundments in forest and pasture	1,413	0.015	5%
Geese[a]	300 ft buffer around main streams	1,070	0.078 – off season 0.1092 – peak season	2.5%
Wood Duck[a]	300 ft buffer around main streams	1,070	0.0624 – off season 0.0936 – peak season	2.5%
Wild Turkey	Entire Watershed except urban and farmstead	11,486	0.01	0.1%

[a] Based on estimates provided by Professional Trapper (R. Spiggle, personal communication, October 2001, Blacksburg, Va.)

Table 4.26. Distribution of wildlife among sub-watersheds.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
LG-01	17	12	6	1	5	5	3
LG-02	14	8	0	1	4	4	3
LG-03	27	16	19	2	11	10	5
LG-04	35	16	2	1	1	0	7
LG-05	7	6	16	1	5	4	2
LG-06	95	47	17	5	23	20	20
LG-07	54	33	18	4	17	14	11
LG-08	84	26	42	2	11	10	18
LG-09	87	32	5	3	11	9	18
Total	420	196	125	20	88	76	87

4.2.7. Summary: Contribution from All Sources

Based on the inventory of sources discussed in this chapter, a summary of the contribution by the different nonpoint sources to direct annual fecal coliform loading to the streams is given in Table 4.27. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 4.27.

From Table 4.27, it is clear that nonpoint source loadings to the land surface are 870 times larger than direct loadings to the streams (not including commercial sources), with pastures receiving about 96% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation amount and pattern, manure application activities (time and method), type of waste (solid versus liquid manure) and proximity to streams also impact the amount of fecal coliform from upland areas that reaches the streams. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 5.

Table 4.27. Annual fecal coliform loadings to the stream and the various land use categories in the Long Glade Run watershed.

Source	Fecal coliform loading ($x10^{12}$ cfu/year)	Percent of total loading
Direct loading to streams		
Cattle in stream	55.7	1%
Wildlife in stream	2.5	<1%
Loading to land surfaces		
Cropland	572	1%
Pasture 1	45,055	88.7%
Pasture 2	3,673	7.2%
Loafing Lots	1,142	2.2%
Residential[a]	206	4%
Forest	92.3	1.8%
Total	50,798	

[a] Includes loads received from both High and Low Density Residential and Farmstead due to failed septic systems and pets.

CHAPTER 5: MODELING PROCESS FOR BACTERIA TMDL DEVELOPMENT

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, modeling process, input data requirements, model calibration procedure and results, and model validation results are discussed.

5.1. Model Description

The TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN, Windows Version (HSPF) (Duda *et al.*, 2001) was used to model fecal coliform transport and fate in the Mossy Creek and Long Glade watersheds. The ArcGIS 8.1 GIS program was used to display and analyze landscape information for the development of input for HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes (Duda et al., 2001). HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from largely impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-modules HYDR and ADCALC within the module RCHRES. While HYDR routes the water through the stream network, ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the GQUAL sub-module within RCHRES module. Fecal coliform bacteria are simulated as a dissolved pollutant using the general constituent pollutant model (GQUAL) in HSPF.

5.2. Selection of Sub-watersheds

5.2.1. Mossy Creek Sub-watersheds

Mossy Creek is a moderately sized watershed (10,072 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into eight sub-watersheds as shown in Figure 5.1. The impaired section of Mossy Creek (VAV-B19R) begins at the headwaters and runs to the confluence with the North River. Small tributaries into Mossy Creek are unnamed. The stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. Because loadings of bacteria are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use.

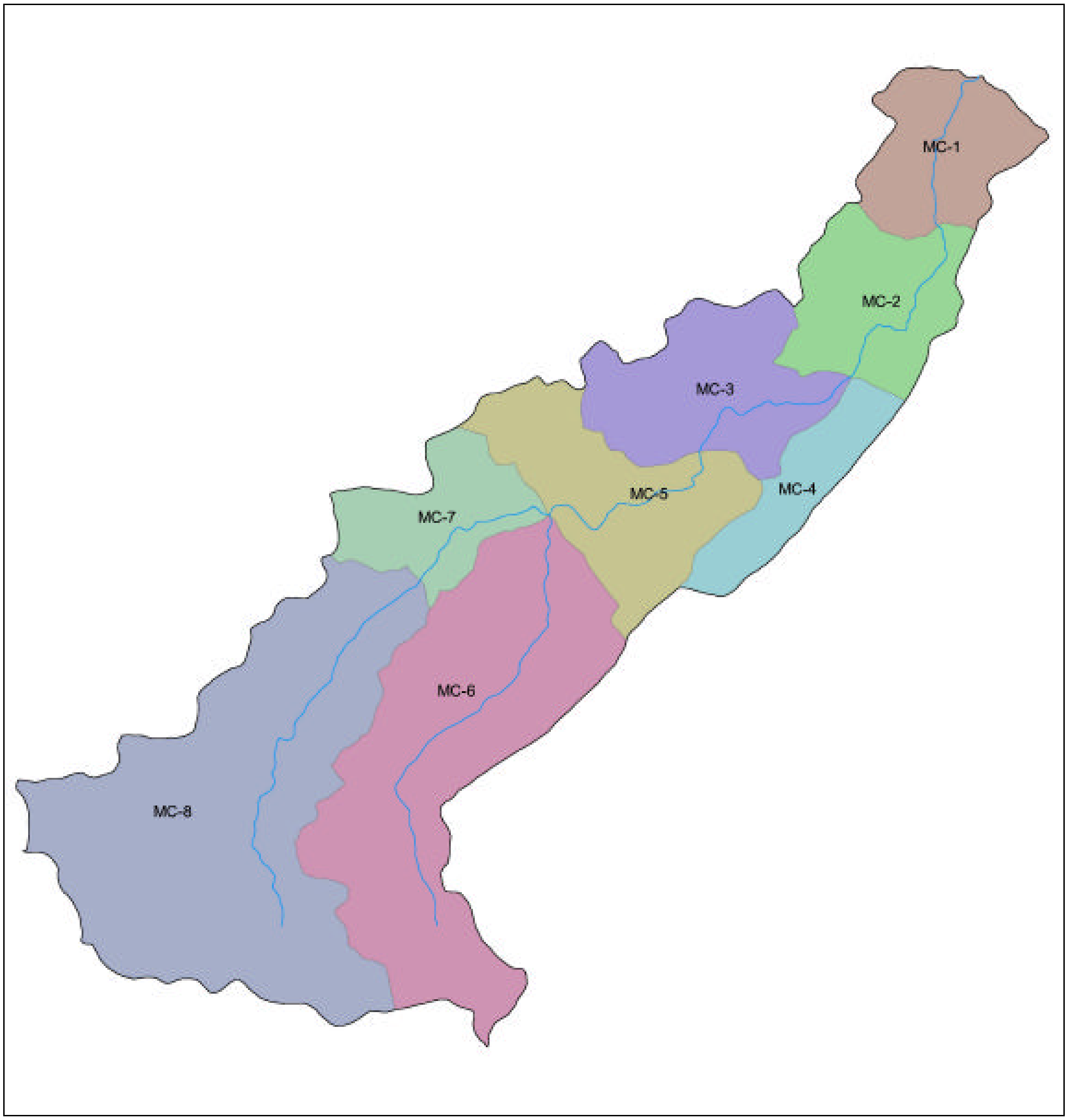

Figure 5.1. Mossy Creek Sub-Watersheds.

5.2.2. Long Glade Run Sub-watersheds

Long Glade Run is a moderately sized watershed (11,843 ac) and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into nine sub-watersheds as shown in Figure 5.2. The impaired stream section runs from the Long Glade Run (VAV-B24R) headwaters to its confluence with the North River.

Small tributaries into Long Glade Run are unnamed. With the exception of the stream segment sub-watershed 4, the stream network was delineated based on the blue line stream network from USGS topographic maps with each sub-watershed having at least one stream segment. The stream segment in sub-watershed 4 is an intermittent stream; however, this sub-watershed was delineated to preserve the stream network and account for the local variability in bacteria loadings. Because loadings of bacteria are believed to be associated with land use activities and the degree of development in the watershed, sub-watersheds were chosen based on uniformity of land use.

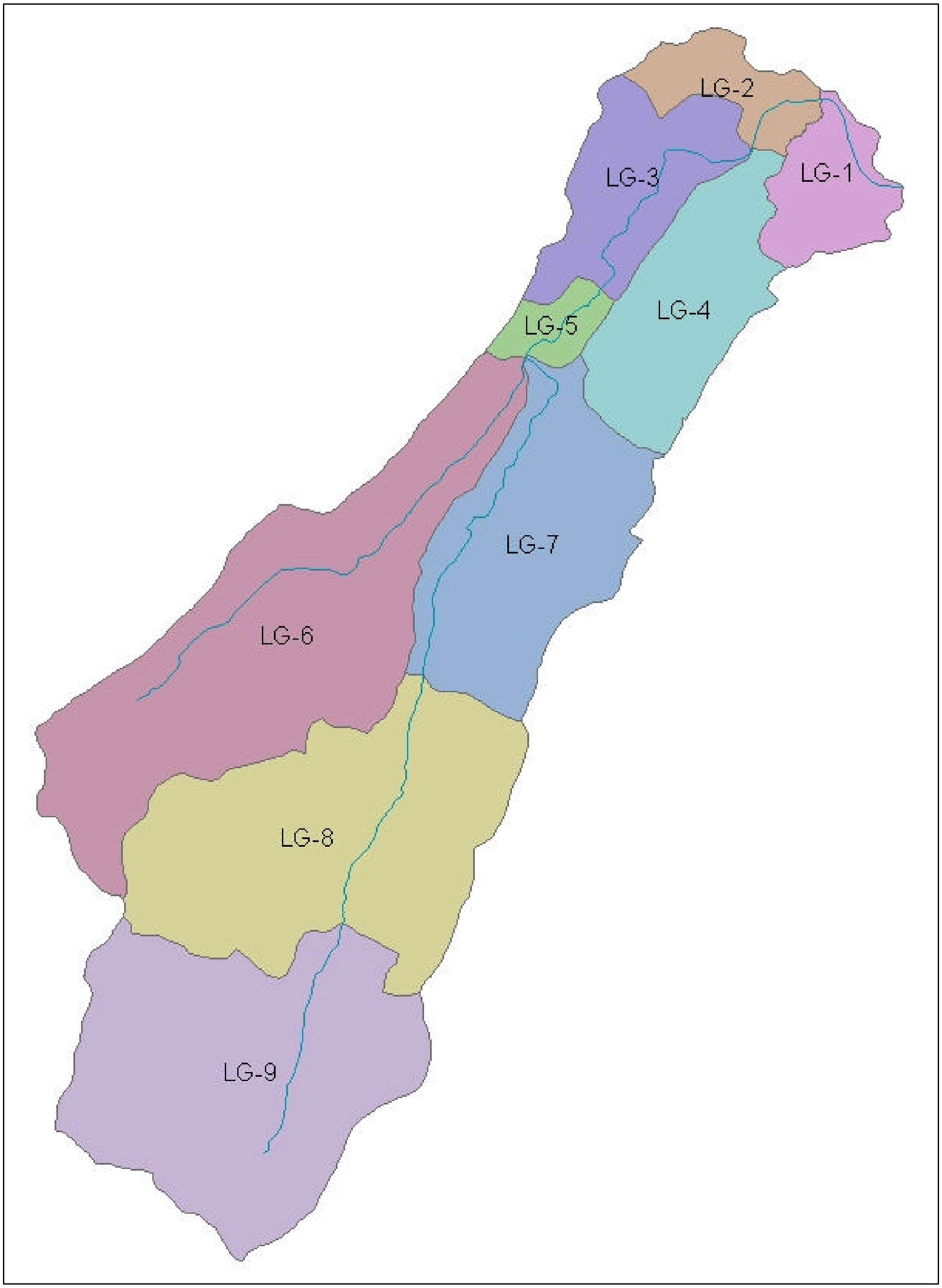

Figure 5.2. Long Glade Run Sub-Watersheds.

5.3. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The different types and sources of input data used to develop the TMDLs for the Mossy Creek and Long Glade Run watersheds are discussed below.

5.3.1. Climatological Data

Weather data needed to conduct simulations were obtained from the weather station closest to the watershed. Hourly precipitation data were obtained from Biological Systems Engineering weather station in the Long Glade Run watershed. Because hourly data for other meteorological parameters, such as solar radiation and temperature, were not available at Biological Systems Engineering weather station, daily measured or simulated data from Dale Enterprise (Virginia), Lynchburg Airport (Virginia), and Elkins Airport (West Virginia) were used to complete the meteorological data set required for running HSPF. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set are described in APPENDIX D.

5.3.2. Hydrology Model Parameters

The hydrology parameters required by PWATER and IWATER were defined for every land use category for each sub-watershed. For each reach, a function table (FTABLE) is required to describe the relationship between water depth, surface area, volume, and discharge (Duda *et al.*, 2001). These parameters were estimated by surveying representative channel cross-sections in each sub-watershed. Information on stream geometry in each sub-watershed of each watershed is presented in Table 5.1. Hydrology parameters required for the PWATER, IWATER, and HYDR ADCALC sub-modules are listed in HSPF Version 11 User's Manual (Bicknell *et al.*, 1997). Parameters required as inputs for PQUAL, IQUAL, and GQUAL are given in the HSPF User's Manual (Bicknell *et al.*, 1997). Runoff estimated by the model is also an input to the water quality components. Values for the parameters were estimated based on local conditions when possible; otherwise the default parameters provided within HSPF were used.

Table 5.1. Stream Characteristics of Mossy Creek.

Sub-watershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
MC-01	1.23	20	2	0.0015
MC-02	1.43	20	2.5	0.0017
MC-03	1.30	15	2	0.0024
MC-04	0.98	2	1	0.0185
MC-05	1.55	15	2	0.0060
MC-06	3.41	3.75	0.57	0.0100
MC-07	1.40	6.5	1.5	0.0004
MC-08	2.10	3.5	1	0.0127

Table 5.2. Stream Characteristics of Long Glade Run.

Sub-watershed	Stream length (mile)	Average width (ft)	Average channel depth (ft)	Slope (ft/ft)
LG-01	1.00	15	4	0.0015
LG-02	0.71	15	4	0.0015
LG-03	1.99	16	4	0.0055
LG-04	2.48	4	0.01	0.0123
LG-05	0.84	11	2.5	0.0051
LG-06	3.91	5	0.13	0.0116
LG-07	2.73	10	2	0.0052
LG-08	1.88	4	0.5	0.0088
LG-09	1.76	6.5	2.56	0.0052

5.3.3. Accounting for Spring Flows In Mossy Creek

As previously mentioned (Section 3.1.1), Mossy Creek has four significant springs that contribute to its flow even during times of drought. With the exception of Mount Solon Spring, the spring inputs were modeled as constant values as shown in Table 5.3. Mount Solon spring flow was varied for two reasons: first, Mount Solon spring had the greatest variation in observed flow rate (Table 5.3); second, it was known that flow from North River contributes to the Mount Solon flow (as described in Section 3.1.1). Therefore, to simulate the variability of the Mount Solon spring flow, flow records from North River for the calibration, validation, and allocation periods were obtained and used in estimating the variability of the flow from Mount Solon Spring, as described in Table 5.3. The 0.02 value multiplied by the North River Flow Rate was determined by dividing the maximum observed flow at the spring (7 cfs) by the maximum observed flow during the calibration period for North River (314 cfs). It is known that the Mount Solon Spring has substantial flow even during periods of low flow in the North River; however, the approximation described above was adequate for modeling purposes, as the hydrology model developed for Mossy Creek using this approximation was acceptably calibrated and validated.

Table 5.3. Discharge Rates of Springs used for Modeling in Mossy Creek.

Spring	Approximate discharge rate (cfs)	Discharge rate used for modeling (cfs)
Mount Solon Spring	3-7	0.02 * North River Flow Rate
Blue Hole	1-3	2
Cress Pond	5-7	6
Kyle's Mill Series	2-3	2.5

5.4. Land Use

5.4.1. Mossy Creek Land Use

Using 1997 aerial photographs, VADCR identified 18 land use types in the watershed. Virginia Tech personnel verified these land uses. The 18 land use types were consolidated into nine categories based on similarities in hydrologic features and waste application/production practices (Table 5.4). These categories were assigned pervious and impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules in HSPF. Land use data were used to select several hydrology and water quality parameter values for the simulations. Land use distribution in the eight sub-watersheds as well as in the entire Mossy Creek watershed is presented in Table 5.5 and graphically in Figure 5.3.

Table 5.4. Consolidation of VADCR land use categories for Mossy Creek watershed.

TMDL Land Use Categories	Pervious/Impervious[a] (Percentage)	VADCR Land Use Categories (Class No.)
Cropland 1	Pervious (100%)	Row Crop, gullied (2110)
Cropland 2	Pervious (100%)	Row Crops, Stripped (2113)
Pasture 1	Pervious (100%)	Improved Pasture/ Permanent Hay (2122) Rotational Hay (2121)
Pasture 2	Pervious (100%)	Unimproved Pasture (2123)
Farmstead	Pervious (85%) Impervious (15%)	Housed Poultry (2321) Farmstead (13) Farmstead with Dairy Waste Facility (813)
Low Density Residential	Pervious (85%) Impervious (15%)	Low Density Residential (12) Mobile Home / RV Park (14) Wooded Residential (44)
High Density Residential	Pervious (70%) Impervious (30%)	Commercial and Services (11) Transportation (7)
Loafing Lot	Pervious (100%)	Loafing Lot (2312)
Forest	Pervious (100%)	Forested (40) Grazed Woodland (3) Water (5)

[a] Percent perviousness/imperviousness information was used in modeling (described in Section 5.4)

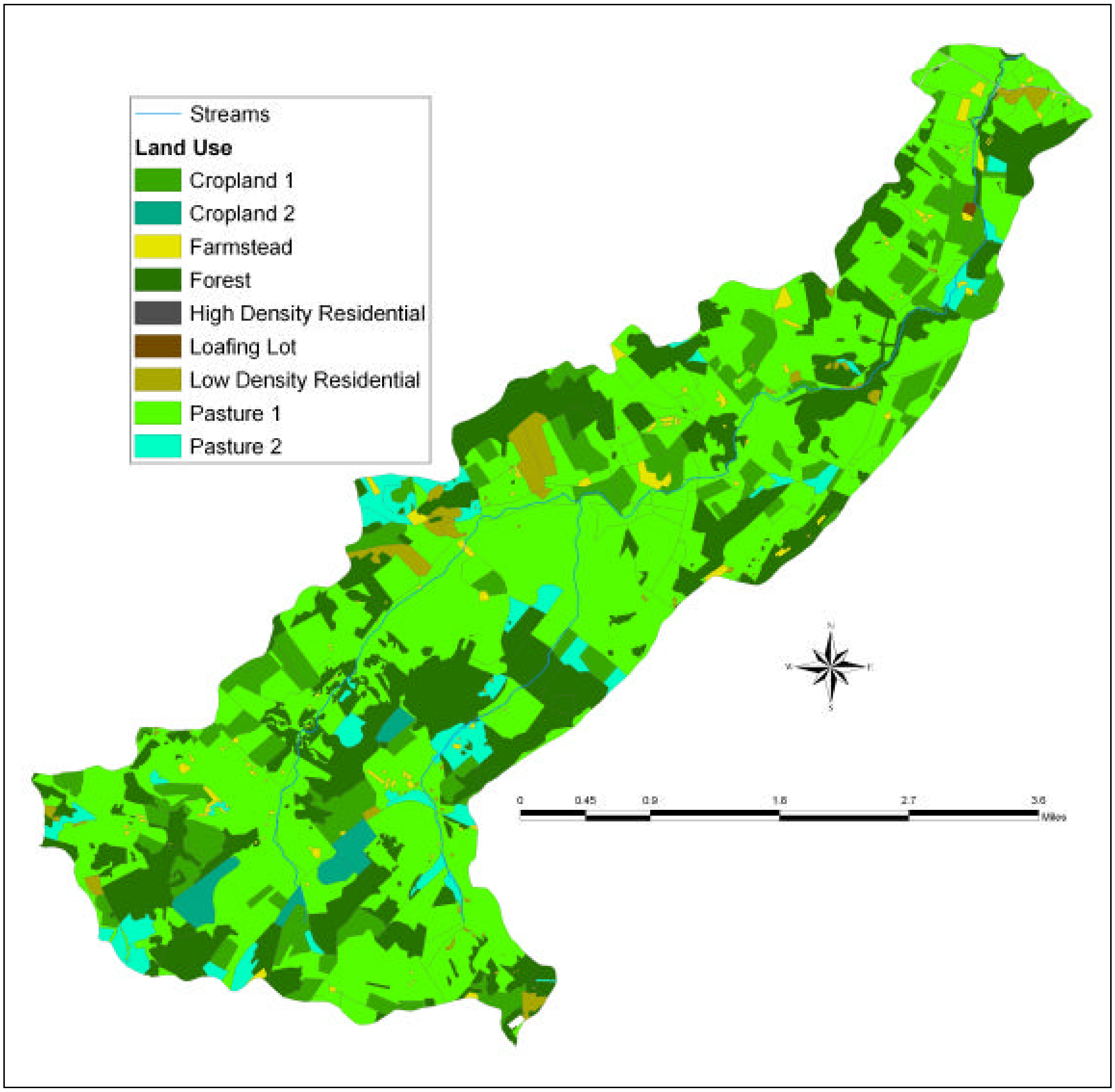

Figure 5.3. Mossy Creek Watershed Land Use.

Table 5.5. Land use distribution in the Mossy Creek watershed (acres).

Land use	Sub-watersheds								
	MC-01	**MC-02**	**MC-03**	**MC-04**	**MC-05**	**MC-06**	**MC-07**	**MC-08**	**Total**
Forest	161	175	289	80	283	637	101	807	**2533**
Cropland 1	63	147	93	67	192	175	58	426	**1219**
Cropland 2	0	0	0	0	0	67	0	88	**155**
Pasture 1	402	411	558	301	510	1312	274	1571	**5339**
Pasture 2	8	32	9	14	8	169	85	138	**462**
Farmstead	22	8	24	7	19	15	15	26	**136**
Low Density Residential	21	2	12	5	33	24	85	33	**215**
High Density Residential	6	0	0	0	0	4	0	0	**9**
Loafing Lot	4	1	0	0	0	0	0	0	**4**
Total	**685**	**776**	**985**	**474**	**1044**	**2402**	**618**	**3089**	**10072**

5.4.2. Long Glade Run Land Use

Using 1997 aerial photographs, VADCR identified 18 land use types in the watershed. Virginia Tech personnel verified these land uses. The 18 land use types were consolidated into nine categories based on similarities in hydrologic and waste application/production features (Table 5.6). These categories were assigned pervious and impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules in HSPF. Land use data were used to select several hydrology and water quality parameter values for the simulations. Land use distribution in the nine sub-watersheds as well as in the entire Long Glade Run watershed is presented in Table 5.7 and graphically in Figure 5.4.

Table 5.6. Consolidation of VADCR land use categories for Long Glade watershed.

TMDL Land Use Categories	Pervious and/or Impervious[a] (Percentage)	VADCR Land Use Categories (Class No.)
Cropland 1	Pervious (100%)	Row Crop, gullied (2110)
Cropland 2	Pervious (100%)	Row Crops, Stripped (2113)
Pasture 1	Pervious (100%)	Improved Pasture/ Permanent Hay (2122) Rotational Hay (2121)
Pasture 2	Pervious (100%)	Unimproved Pasture (2123)
Farmstead	Pervious (85%) Impervious (15%)	Housed Poultry (2321) Farmstead (13) Farmstead with Dairy Waste Facility (813)
Low Density Residential	Pervious (85%) Impervious (15%)	Low Density Residential (12) Mobile Home / RV Park (14) Wooded Residential (44)
High Density Residential	Pervious (70%) Impervious (30%)	Commercial and Services (11) Transportation (7)
Loafing Lot	Pervious (100%)	Loafing Lot (2312)
Forest	Pervious (100%)	Forested (40) Grazed Woodland (3) Water (5)

[a] Percent perviousness/imperviousness information was used in modeling (described in Section 5.4)

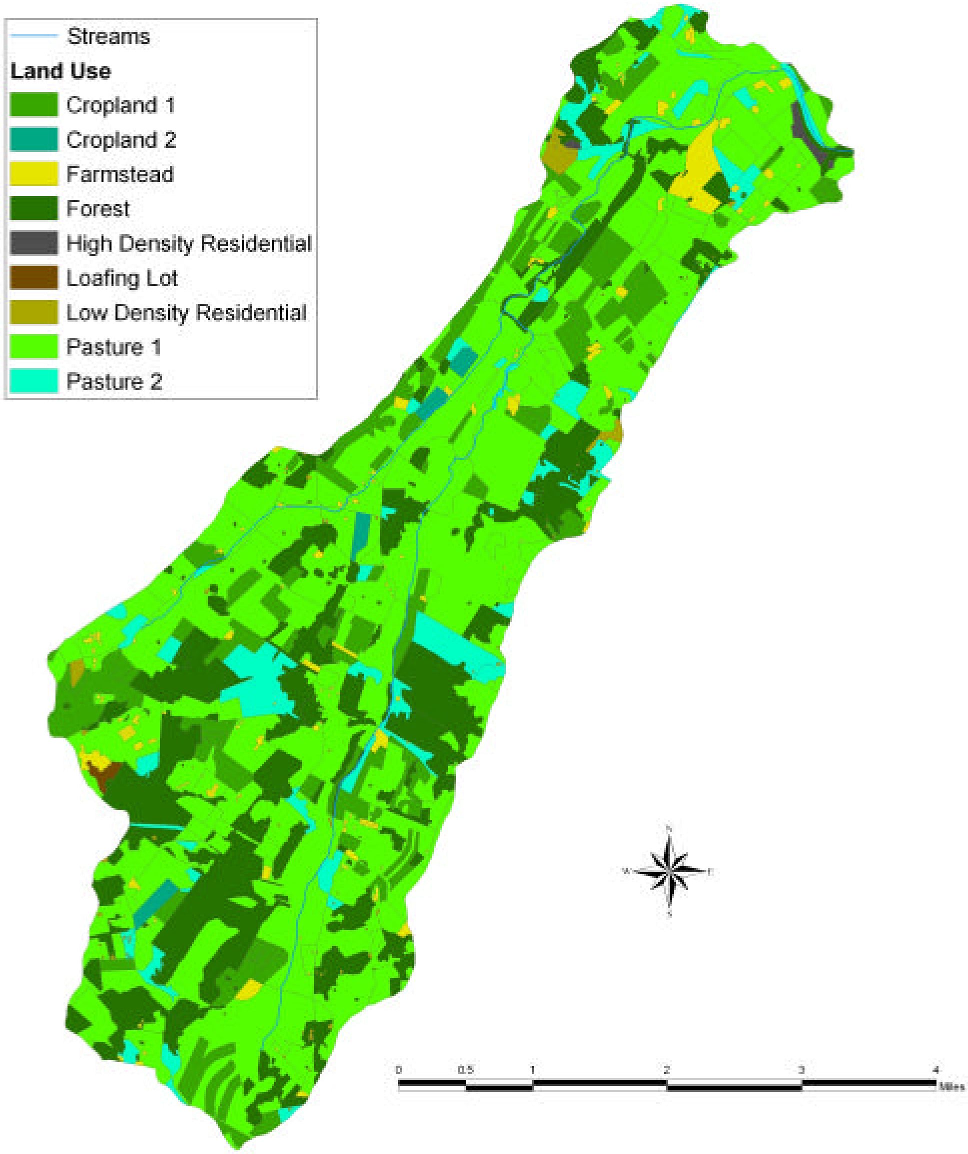

Figure 5.4. Long Glade Run Watershed Land Use.

Table 5.7. Land use distribution in the Long Glade Run watershed (acres).

Land use	Sub-watersheds									
	LG-01	**LG-02**	**LG-03**	**LG-04**	**LG-05**	**LG-06**	**LG-07**	**LG-08**	**LG-09**	**Total**
Forest	37	38	158	77	56	468	264	812	710	**2620**
Cropland 1	39	29	111	217	39	479	104	262	232	**1512**
Cropland 2	0	0	0	0	0	58	0	0	29	**87**
Pasture 1	305	255	355	571	93	1445	1036	1024	1371	**6455**
Pasture 2	50	39	87	19	6	136	102	255	97	**791**
Farmstead	13	11	16	102	2	50	13	34	27	**268**
Low Density Residential	1	0	33	0	0	13	13	1	6	**67**
High Density Residential	22	0	4	0	0	0	0	0	0	**26**
Loafing Lot	0	0	0	0	0	17	0	0	0	**17**
Total	**467**	**372**	**764**	**986**	**196**	**2666**	**1532**	**2388**	**2472**	**11843**

5.5. Accounting for Pollutant Sources

5.5.1. Overview

There were 4 VADEQ permitted bacteria point sources in the Mossy Creek and Long Glade Run watersheds. All 4 of the permitted sources were general permits for facilities/residences discharging at or less than 1000 gallons per day (Table 4.1).

Bacteria loads that are directly deposited by cattle and wildlife in streams were treated as direct nonpoint sources in the model. Bacteria that were land-applied or deposited on land were treated as nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate. The point sources permitted to discharge bacteria in the watershed were incorporated into the simulations at the stream locations designated in the permit.

The nonpoint source loading was applied in the form of fecal coliform counts to each land use category in a sub-watershed on a monthly basis. Fecal coliform die-off was simulated while manure was being stored, while it was on the land, and while it was transported in streams. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

We developed a spreadsheet program internally and used it to generate the nonpoint source fecal coliform inputs to the HSPF model. This spreadsheet program takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. We customized the program to allow direct deposition in the stream by dairy cows, ducks, and geese to occur only during daylight hours. The spreadsheet program calculates the manure produced in confinement by each animal type (dairy cows, beef cattle, and poultry) and distributes this manure to available lands (crops and pasture) within each sub-watershed. If a sub-watershed does not have sufficient land to apply all the manure its animals generate, the excess manure is distributed equally to other sub-watersheds that have land that has not yet received manure. In Mossy Creek and Long Glade Run, however, there was sufficient land available in each sub-watershed such that all manure generated within a sub-watershed could be applied in the same sub-watershed.

5.5.2. Modeling fecal coliform die-off

Fecal coliform die-off was modeled using first order die-off of the form:

$$C_t = C_0 10^{-Kt} \qquad [5.1]$$

where: C_t = concentration or load at time t,

C_0 = starting concentration or load,

K = decay rate (day^{-1}),

and t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the Mossy Creek and Long Glade Run watersheds (Table 5.8).

Table 5.8. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources.

Waste type	Storage/application	Decay rate (day^{-1})	Reference
Dairy manure	Pile (not covered)	0.066	Jones (1971)[a]
	Pile (covered)	0.028	
Beef manure	Anaerobic lagoon	0.375	Coles (1973)[a]
Poultry litter	Soil surface	0.035	Giddens *et al*. (1973)
		0.342	Crane *et al*. (1980)

[a] Cited in Crane and Moore (1986)

Based on the values cited in the literature, the following decay rates were used in simulating fecal coliform die-off in stored waste.

- Liquid dairy manure: Because the decay rate for liquid dairy manure storage could not be found in the literature, the decay rate for beef manure in anaerobic lagoons (0.375 day^{-1}) was used.

- Solid cattle manure: Based on the range of decay rates (0.028-0.066 day^{-1}) reported for solid dairy manure, a decay rate of 0.05 day^{-1} was used assuming that a majority of manure piles are not covered.

- Poultry waste in pile/house: Because no decay rates were found for poultry waste in storage, a decay rate of 0.035 day^{-1} was used based on the lower decay rate reported for poultry litter applied to the soil surface. The lower value was used instead of the higher value of 0.342 day^{-1} (Table 5.8) because fecal coliform die-off in storage was assumed to be lower, given the absence of UV radiation and predation by soil microbes.

The procedure for calculating fecal coliform counts in waste at the time of land application is included in APPENDIX C. Depending on the duration of storage, type of storage, type of manure, and die-off factor, the fraction of fecal coliform surviving in the manure at the end of storage is calculated. While calculating survival fraction at the end of the storage period, the daily addition of manure and coliform die-off of each fresh manure addition is considered to arrive at an effective survival fraction over the entire storage period. The amount of fecal coliform available for application to land per year is estimated by multiplying the survival fraction with total fecal coliform produced per year (in as-excreted manure). Monthly fecal coliform application to land is estimated by multiplying the amount of fecal coliform available for application to land per year by the fraction of manure applied to land during that month. A decay rate of 0.045 day^{-1} was assumed for fecal coliform on the land surface. The decay rate of 0.045

day^{-1} is represented in HSPF by specifying a maximum surface buildup of nine times the daily loading rate. An in-stream decay rate of 2.30 day^{-1} was used.

5.5.3. Modeling Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 4:. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, and human populations and fecal coliform production rates. Fecal coliform in stored waste was adjusted for die-off prior to the time of land application when calculating loadings to cropland and pasture. For a given period of storage, the total amount of fecal coliform present in the stored manure was adjusted for die-off on a daily basis. Fecal coliform loadings to each sub-watershed in the Mossy Creek and Long Glade Run watersheds are presented in APPENDIX F. The sources of fecal coliform to different land use categories and how the model handled them are briefly discussed below.

1. Cropland: Liquid dairy manure and solid manure are applied to cropland as described in Chapter 4:. Fecal coliform loadings to cropland were adjusted to account for die-off during storage and partial incorporation during land-application. Wildlife contributions were also added to the cropland areas. For modeling, monthly fecal coliform loading assigned to cropland was distributed over the entire cropland acreage within a sub-watershed. Thus, loading rate varied by month and sub-watershed.

2. Pasture: In addition to direct deposition from livestock and wildlife, pastures receive applications of liquid dairy manure and solid manure as described in Chapter 4:. Applied fecal coliform loading to pasture was reduced to account for die-off during storage. For modeling, monthly fecal coliform loading assigned to pasture was distributed over the entire pasture acreage within a sub-watershed.

3. Loafing Lot: Loafing lots receive manure deposited by cows during the time they spend on the loafing lots (Table 4.7, Table 4.8, Table 4.20, and Table 4.21). Fecal coliform loads resulting from direct waste deposition by cows in a particular sub-watershed are distributed uniformly over the entire loafing lot acreage in each sub-watershed.

4. Low Density Residential and Farmstead: Fecal coliform loading on rural residential and Farmstead land use came from failing septic systems, wildlife and waste from pets. In the model simulations, fecal coliform loads produced by failing septic systems and pets in a sub-watershed were combined and assumed to be uniformly applied to the low density residential pervious land use areas. Impervious areas (Table 5.4 and Table 5.6) received constant loads of 1.0×10^{7} cfu/acre/day.

5. High-Density Residential: Fecal coliform loading to the high density residential land use came from pets in these areas; the impervious load was assumed to be a constant 1.0×10^{7} cfu/acre/day (USEPA, 2000).

6. Forest: Wildlife not defecating in streams, cropland, and pastures provided fecal coliform loading to the forested land use. Fecal coliform from wildlife in forests was applied uniformly over the forest areas.

5.5.4. Modeling Direct Nonpoint Sources

Fecal coliform loads from direct nonpoint sources included cattle in streams, wildlife in streams, and direct loading to streams from straight pipes from residences. Loads from direct nonpoint sources in each sub-watershed are described in detail in Chapter 4. Contributions of fecal coliform from interflow and groundwater were modeled as having a constant concentration of 30 cfu/100mL for interflow and 20 cfu/100mL for groundwater.

In Mossy Creek, springs provided additional sources of bacteria to the watershed. Although the area contributing to Mossy Creek through the spring inputs (particularly Mount Solon spring) was investigated through the dye trace studies described previously (Section 3.1.1), and potentially includes the area in the ‘Karst Watershed’ shown in Figure 5.5, the specific effects of the karst topography on fecal bacteria concentrations are not known. Detailed, definitive relations between hydrologic events and bacteria loading to Mossy Creek from the extended karst watershed were not definitively determined by the dye tracer studies discussed earlier.

Therefore, rather than attempting to quantify bacteria sources that contributed to the springs in the Mossy Creek watershed, the springs were treated as direct nonpoint source fecal coliform inputs to Mossy Creek. The geometric means of the observed fecal coliform concentrations shown in Table 3.3 were used as constant input concentrations for their respective springs. Because the Mount Solon Spring flow is variable, the load coming from that spring is also variable despite the constant fecal coliform concentration.

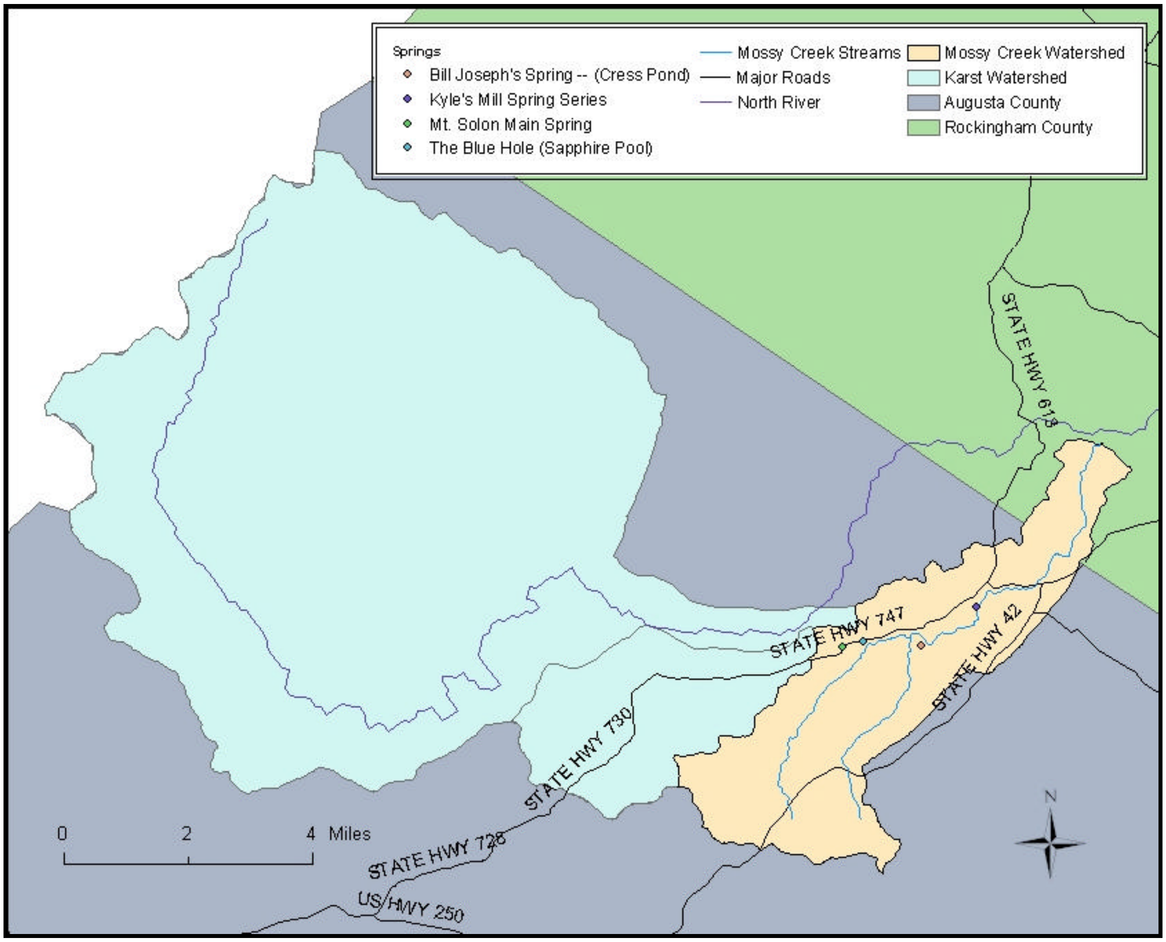

Figure 5.5. Areas of Potential Contribution to Mossy Creek Springs.

5.6. Model Calibration and Validation

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. Validation ensures that the calibrated parameters are appropriate for time periods other than the calibration period. In this section, the procedures followed for calibrating the hydrology and water quality components of the HSPF model are discussed. The calibration and validation results of the hydrology component and the calibration results of the water quality component are presented.

5.6.1. Mossy Creek

5.6.1.a. Hydrology

The hydrologic calibration period was September 1, 1998 to December 31, 1999. The hydrologic validation period was from January 1, 2000 to September 30, 2002. The output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range.

The HSPEXP decision support system developed by USGS was used to calibrate the hydrologic portion of HSPF for Mossy Creek. The default HSPEXP criteria for evaluating the accuracy of the flow simulation were used in the calibration for Mossy Creek. These criteria are listed in Table 5.9. After calibration, all criteria listed in Table 5.9 were met.

Table 5.9. Default criteria for HSPEXP.

Variable	Percent Error
Total Volume	10%
50 % Lowest Flows	10%
10 % Highest Flows	15%
Storm Peaks	15%
Seasonal Volume Error	10%
Summer Storm Volume Error	15%

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Figure 5.6 and Figure 5.7. The agreement with observed flows is further illustrated in Figure 5.8 and Figure 5.9 for a representative year and Figure 5.10 and Figure 5.11 for a representative storm. Hourly weather data from the BSE precipitation station, PLC (Figure 3.2), was primarily used for this simulation. This weather station is located in the Long Glade watershed and collected hourly rainfall during the calibration and validation periods.

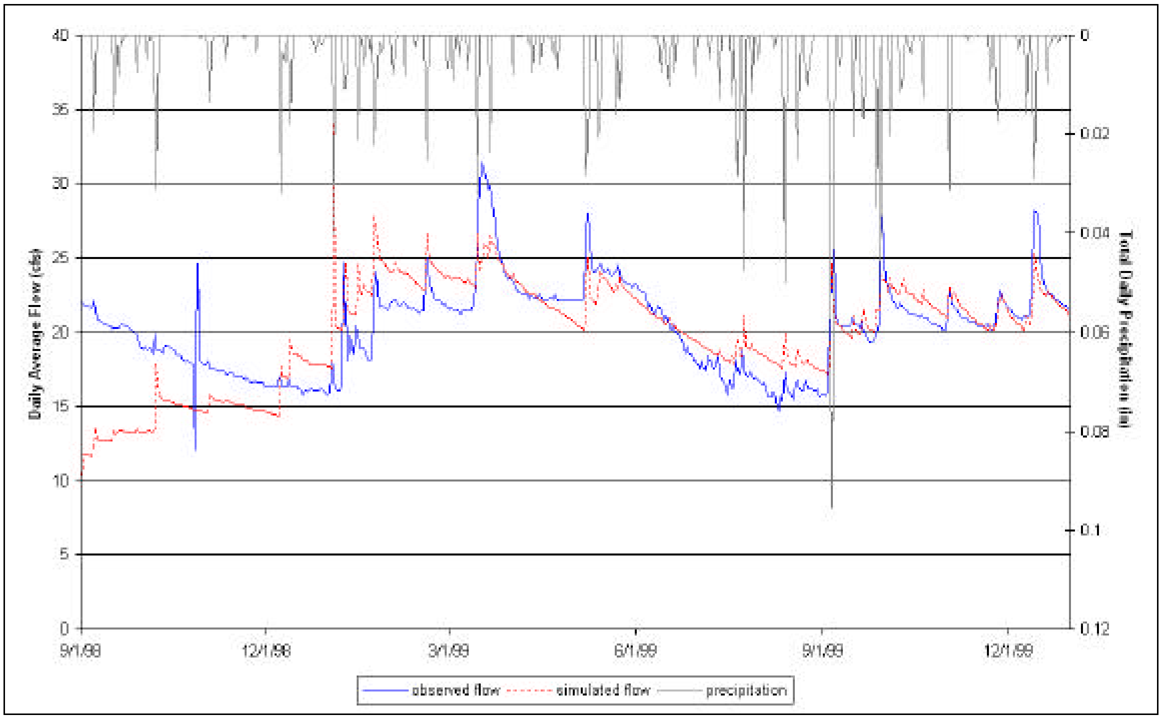

Figure 5.6.Observed and simulated flows and precipitation for Mossy Creek for the calibration period.

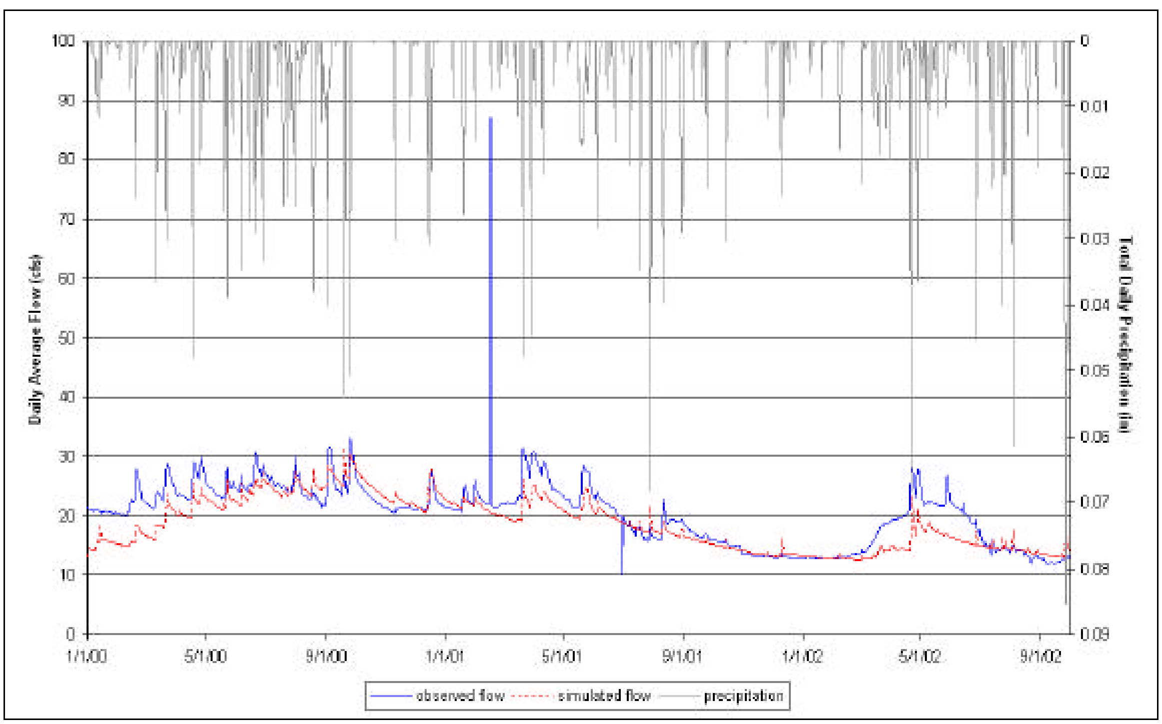

Figure 5.7. Observed and simulated flows and precipitation for Mossy Creek during the validation period.

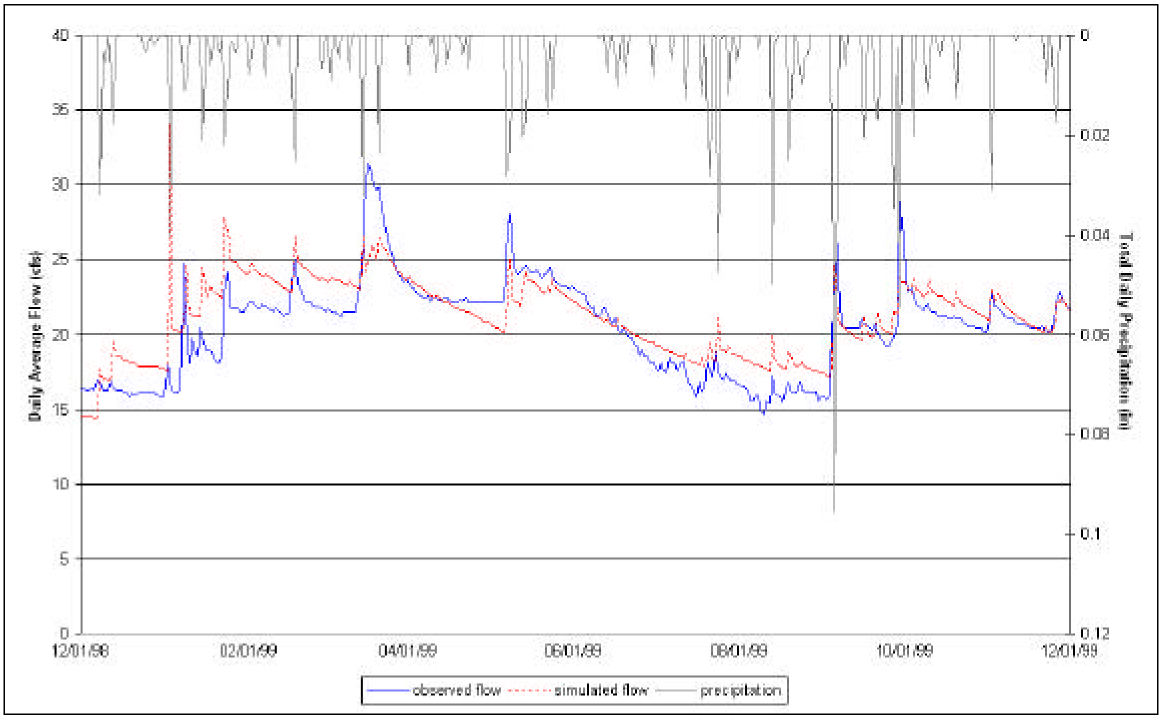

Figure 5.8. Observed and simulated flows and precipitation for a representative year in the calibration period for Mossy Creek.

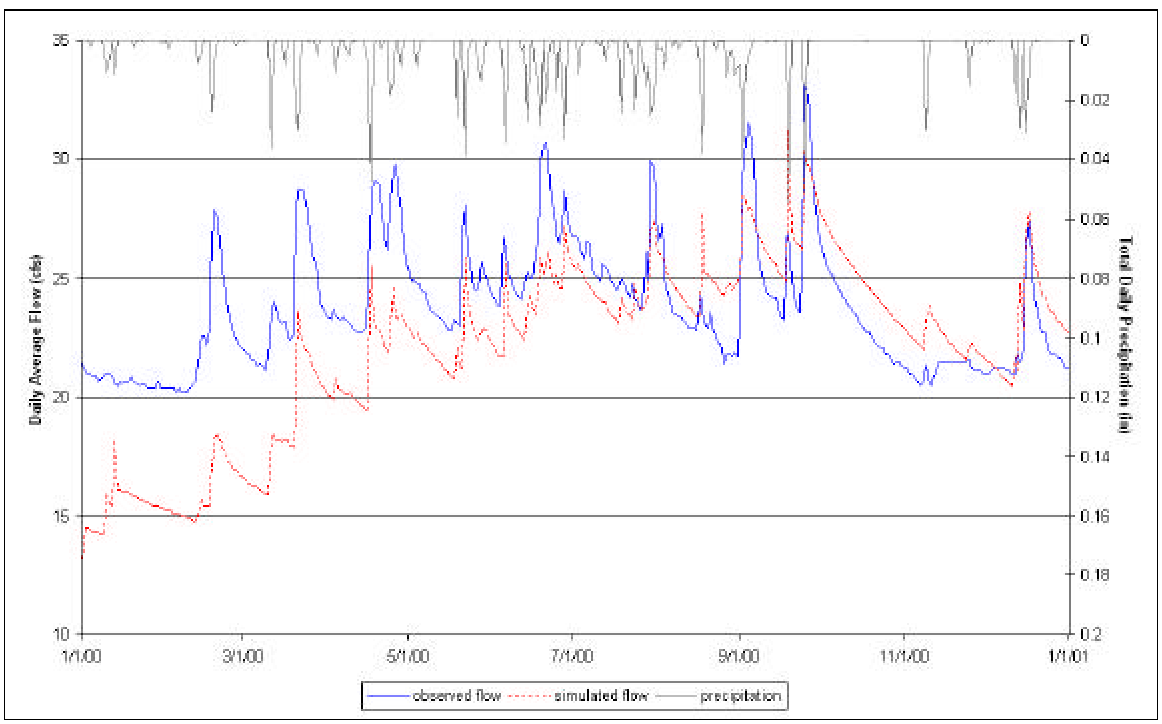

Figure 5.9. Observed and simulated flows and precipitation for Mossy Creek during a representative year in the validation period.

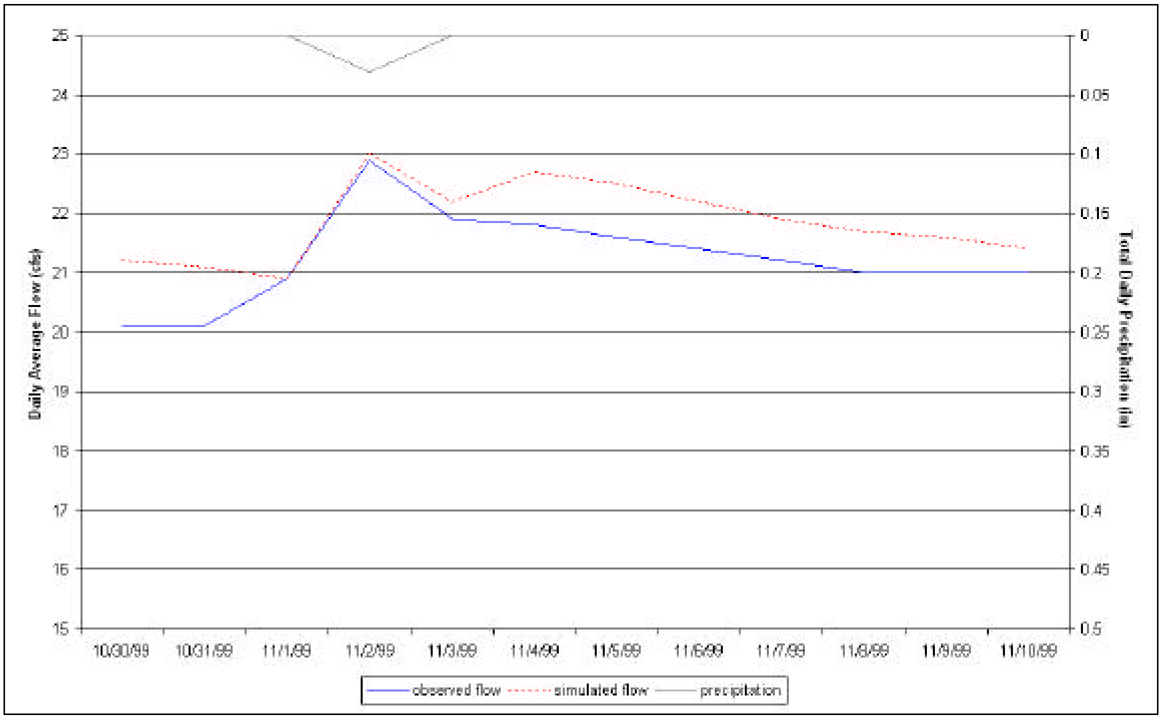

Figure 5.10.Observed and simulated flows and precipitation for Mossy Creek for a representative Storm in the calibration period.

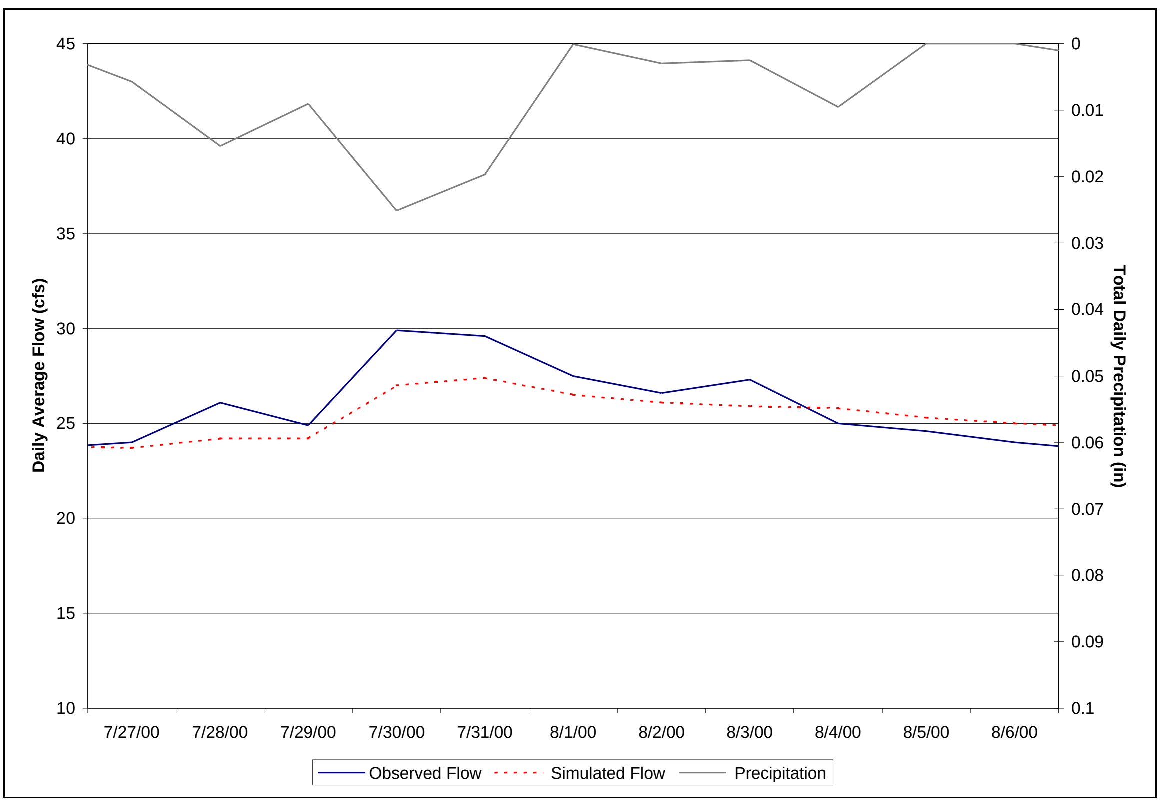

Figure 5.11. Observed and simulated flows, and precipitation for Mossy Creek for a representative storm in the validation period.

The excellent agreement between the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figure 5.12 and Figure 5.13).

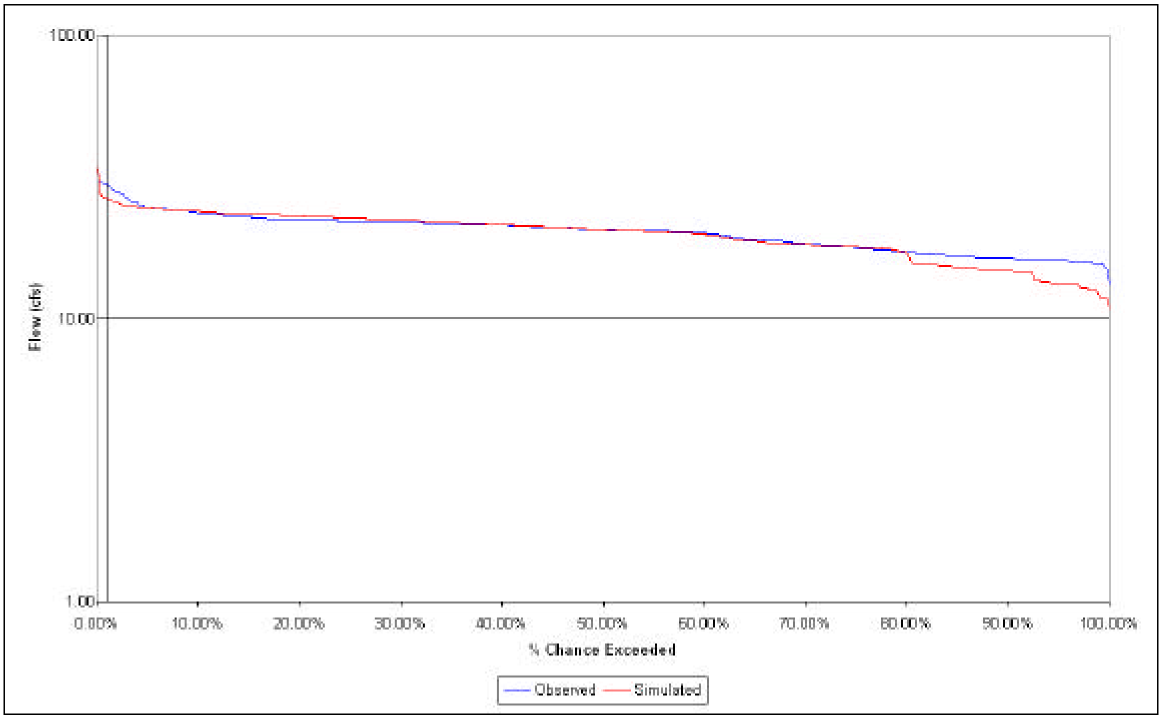

Figure 5.12. Cumulative frequency curves for the calibration period for Mossy Creek.

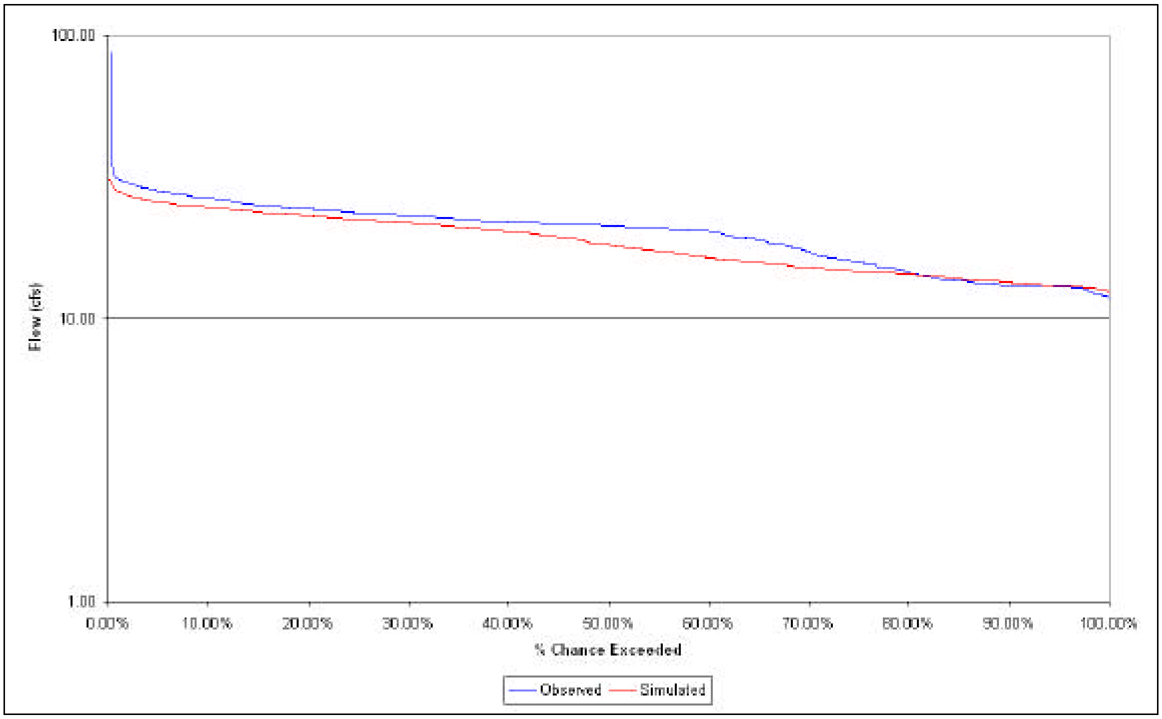

Figure 5.13. Cumulative frequency curves for the validation period for Mossy Creek.

As previously mentioned, the expert system HSPEXP was used to assist with calibrating and validating the Mossy Creek hydrologic model. Selected diagnostic output from the program is listed in Table 5.10 and Table 5.11. The total winter runoff and total summer runoff errors are considered in the HSPEXP term 'seasonal volume error' (see Table 5.9). The errors for seasonal volume error were 0.2% for the calibration period and 7.3% for the validation period; both are within the required range of ± 10%.

Table 5.10. Summary statistics for the calibration period for Mossy Creek.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	24.630	25.081	-1.8	10%
Average Annual Total Runoff	18.460	18.798	-1.8	10%
Total of Highest 10% of flows	3.040	3.145	-3.3	15%
Total of Lowest 50% of flows	10.570	11.111	-4.9	15%
Total Winter Runoff	6.570	6.162	+6.6	na
Total Summer Runoff	0.350	0.347	+0.9	na
Coefficient of Determination, r^2	0.38			

na = not applicable; these are not criteria directly considered by HSPEXP

Table 5.11. Summary statistics for the validation period for Mossy Creek.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	47.660	52.106	-8.5	10%
Average Annual Total Runoff	17.344	18.962	-8.5	10%
Total of Highest 10% of flows	6.620	7.581	-12.7	15%
Total of Lowest 50% of flows	18.960	20.845	-9	15%
Total Winter Runoff	10.420	11.754	-11.3	na
Total Summer Runoff	1.130	1.231	-8.2	na
Coefficient of Determination, r^2	0.52			

na = not applicable; these were not criteria directly considered by HSPEXP

Flow partitioning for Mossy Creek hydrologic model calibration and validation is shown in Table 5.12. When the observed flow data were evaluated using HYSEP, the baseflow indices for the calibration and validation periods were 0.97 and 0.96 respectively. We believe the simulated baseflow indices shown in Table 5.12 match these observed values well.

Table 5.12. Flow partitioning for the calibration and validation periods for Mossy Creek.

Average Annual Flow	Calibration	Validation
Total Annual Runoff (in)	24.630	47.660
Surface Runoff (in)	0.200 (0.8%)	0.290 (0.6%)
Interflow (in)	0.490 (2%)	0.350 (0.7%)
Baseflow (in)	23.94 (97.2%)	47.02 (98.7%)
Baseflow Index	0.97	0.99

A list of final calibration parameters for both the hydrology and water quality simulations can be found at the end of the next section (Table 5.17).

5.6.1.b. Water Quality calibration

Direct Deposition of Manure at Very Low Flows

We modeled direct deposition of manure in streams by livestock considering stream depth. Fecal coliform inputs by livestock in streams are typically simulated without regard to stream depth. Under extreme low flow conditions, one animal defecating once in a stream reach can result in a violation of the instantaneous water quality standard; however, under such extreme low flows, it is not likely for animals to wade in or drink from the stream. Therefore, modeled direct deposition of manure by livestock at extreme low flow conditions can cause unrealistically high numbers of violations, make calibration difficult, and adversely affect the quality of the final calibration.

In order to more accurately model the water quality conditions in Mossy Creek, we used a stage (stream depth) of 3 inches as a cutoff for cattle direct deposition of manure. When the stream depth was less than 3 inches, direct deposition by cattle was set to zero; at stream depth values greater than 3 inches, direct deposition was left unchanged. In order to test the validity of this assumption, HSPF was run with the original direct deposit inputs and with the 3-inch stage cutoff direct deposit values using calibrated values for water quality parameters. Values for the instantaneous violations and geometric means of the simulated data as compared with the data observed at the VADEQ monitoring station are given in Table 5.13. The simulated values using the 3-inch stage cutoff for direct deposition were closer to the observed data than the simulated values where no stream cutoff was used. This is expected, as direct deposition of manure at very low flows can cause a large numbers of violations.

Table 5.13. Simulated and Observed Water Quality Characteristics

	Geometric Mean	Instantaneous Violations
Observed (VADEQ)	442	54%
Simulated with - 3 in cutoff	761	73%
Simulated without cutoff	872	76%

To be completely accurate, the fecal coliform direct deposit loading removed as a result of the cutoff should be reapplied to the pasture area (cattle not wading and defecating in the stream will have to graze and defecate on the pasture). For the purpose of modeling, if the fecal coliform loading removed by the 3-in. stage cutoff was greater than 1% of the total pasture-applied fecal coliform loading, it would be reapplied to the land in the model. Otherwise, this loading would be considered insignificant with respect to the loadings on the land. Table 5.14 compares the total cattle direct deposit fecal coliform loading simulated at the outlet of each reach with and without the 3-in. cutoff. The difference in these values was assumed to be the amount of fecal coliform 'lost' by imposing the cutoff. For subwatersheds with a difference in direct deposit loadings, the amount of fecal coliform applied to pasture (through manure application, cattle deposits, and wildlife deposits) was calculated. If the amount of fecal coliform 'lost' was greater than 1% of the total pasture applied fecal coliform loading, the 'lost' quantity of manure would be reapplied to pasture in the model. However, for Mossy Creek, only subwatershed 8 had any difference in total fecal coliform loadings, and this value was only 0.02% of the fecal coliform load received by pasture in that subwatershed. Also, the 'lost' fecal coliform numbers were so small compared to the loadings already being applied to the pasture that, were they added to the pasture loading in the ACCUM table, they would not change the number used in the ACCUM table given the significant figure limitation of the HSPF UCI file. Therefore, no manure had to be reapplied to the pasture areas.

Table 5.14. Details on 'Lost' Fecal Coliform for the Calibration Period

Reach	Direct Deposit loading w/o cutoff	Direct Deposit loading w/ 3 inch cutoff	Difference in Direct Deposit loadings ('Lost' FC)	Pasture-Applied Fecal Coliform by Subwatershed	Percent 'Lost' FC is of Pasture-Applied FC
1	5.88E+12	5.88E+12	0.00E+00	*	0.00%
2	3.14E+13	3.14E+13	0.00E+00	*	0.00%
3	5.15E+13	5.15E+13	0.00E+00	*	0.00%
4	0.00E+00	0.00E+00	0.00E+00	*	0.00%
5	4.75E+13	4.75E+13	0.00E+00	*	0.00%
6	2.98E+14	2.98E+14	0.00E+00	*	0.00%
7	1.73E+13	1.73E+13	0.00E+00	*	0.00%
8	3.26E+14	1.94E+14	1.32E+14	6.15947E+17	0.02%

*- not calculated because 'lost' FC was equal to zero

Using a 3-inch stage cutoff for manure deposition by cattle reduces the possibility of unrealistic instantaneous violations, resulting in a more accurate description of the fecal coliform concentration in the stream. Because this fecal coliform load was an insignificant portion of the total fecal coliform loading to pastures, there was no need to reapply the load to pasture lands within the watersheds. Consequently, the 3-inch stage cutoff method was used for the calibration and allocation scenarios for the Mossy Creek watershed.

Mossy Creek Calibration using 3-inch Stage Direct Deposition Cutoff

The water quality calibration was performed at an hourly time step using the HSPF model. The water quality calibration period was September 1, 1998 through September 30, 2002. Output from the HSPF model was generated as an hourly timeseries and daily average timeseries of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \quad [5.1]$$

The *E. coli* translator was implemented in the HSPF simulation using the GENER block. The geometric mean was calculated on a monthly basis. The BST results for Mossy Creek are shown in Table 5.15. Table 5.16 contains the simulated percent contributions from the major source categories to the instream load during the calibration period.

Table 5.15. Bacterial source tracking results at the Mossy Creek Station.

Month	% Human	% Domestic	% Wild
Range	0-44	40-90	0-50
Average	16	58	25

Table 5.16. Simulated percent contributions from major source categories for Mossy Creek during the calibration period.

Scenario	Livestock DD	Livestock Land	Wildife DD	Wildlife Land	Septic/ Straight Pipe	Cats/ Dogs	Impervious	Interflow and Groundwater	Springs
Total period	47.65%	41.66%	3.61%	0.12%	1.65%	0.57%	0.91%	1.59%	2.24%

DD = direct deposit

Examining Table 5.15 and Table 5.16 one sees that most of the simulated source category contributions fall within the ranges specified by the BST data. Considering that the period in which BST data was collected was one of drought, and that the simulated period encompassed this period as well as some non-drought conditions, a little leeway on the interpretation of the BST data can be granted. The ‘domestic’ sources for the BST data include livestock and pets. Depending on whether one was measuring during a time of no rainfall or directly after a storm runoff event, one might expect the livestock land deposits and livestock direct deposits to alternately dominate and fall within the range of the BST predictions at any given time. The combined contributions from straight pipes and septic systems fall within the observed range of data for human sources; the low percent contributions from straight pipes would become more dominant during non-storm runoff periods. The wildlife values also fall within the observed range of data for wildlife sources, and again the direct deposit contributions would become more dominant during non-storm runoff periods.

In addition to correlating well with the BST results, the simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations. Figure 5.14 shows the daily average simulated fecal coliform concentrations and the observed data from the DEQ sampling station. Figure 5.15 shows the daily average simulated fecal coliform concentrations and the observed data from the BSE sampling station. At the DEQ sampling station the maximum observed concentration was a capped value of 8,000 cfu/100 mL; at the BSE sampling station the maximum observed concentration was a capped value of 160,000 cfu/100 mL. The overall maximum simulated concentration was 333,000 cfu/100 mL.

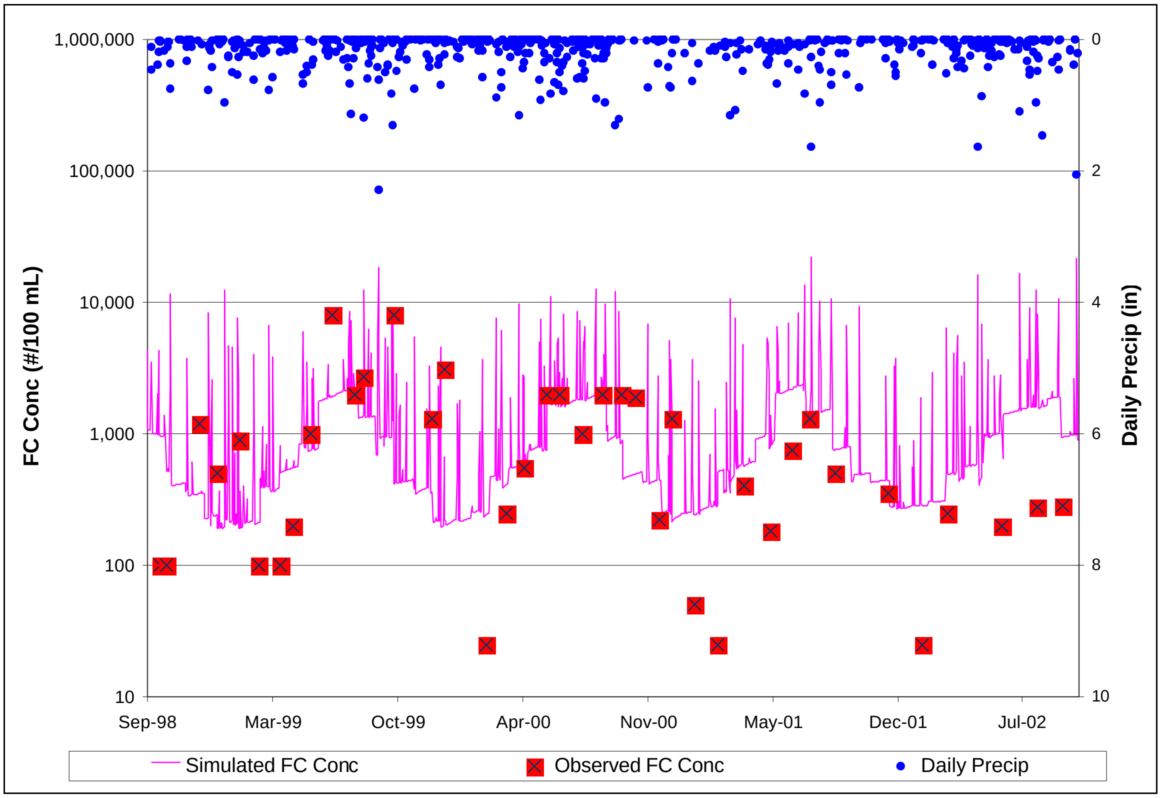

Figure 5.14. Observed Concentrations and Simulated Fecal Coliform Concentrations at the DEQ Monitoring Station for the Water Quality Calibration Period.

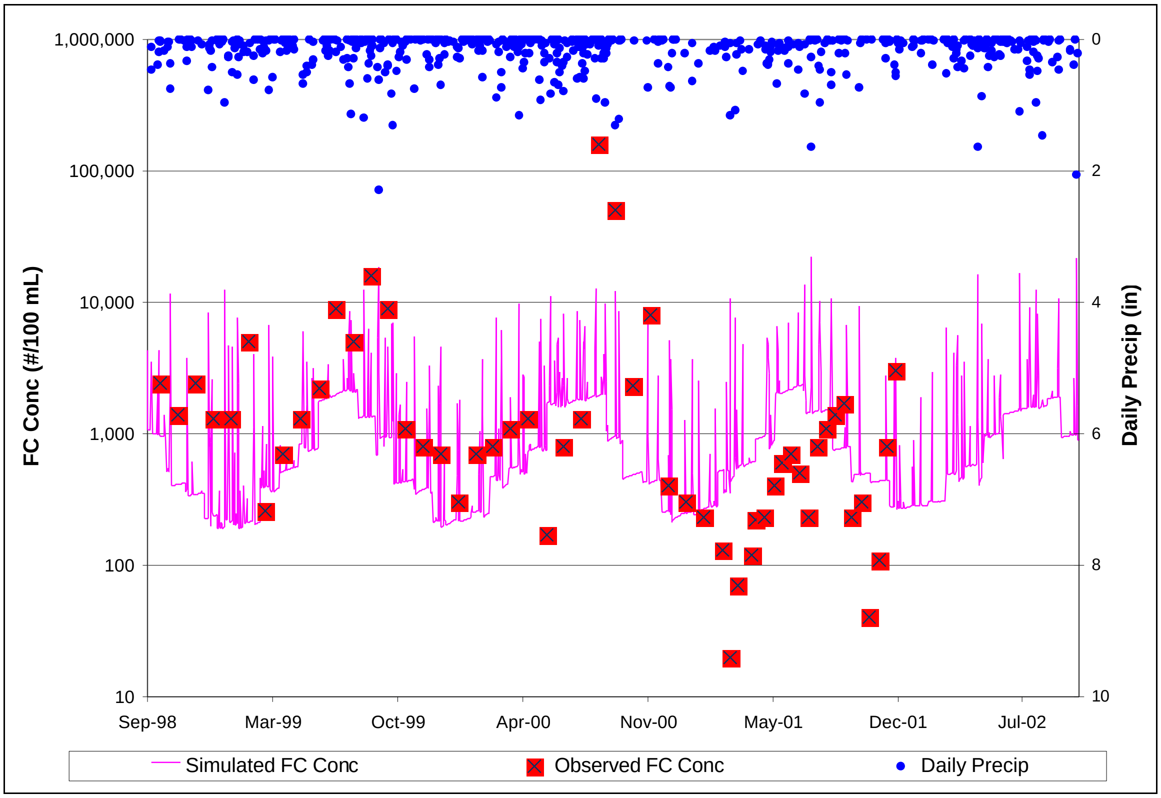

Figure 5.15. Observed Concentrations and Simulated Fecal Coliform Concentrations at the BSE Monitoring Station for the Water Quality Calibration Period.

In addition to the daily average simulated concentrations presented in the previous figures, a 'five-day window' was considered when performing the water quality calibration. Because the observed values are point-values and represent only an instant in time, it is not reasonable to expect the simulated daily arithmetic mean fecal coliform concentration to exactly match the observed value on a particular day. It is more reasonable to assume that at some point during a window of time surrounding the observed point, the model will simulate a concentration close to that observed. For this reason, we developed a 'five-day window' that considers the minimum and maximum simulated values from the 2 days before to the 2 days after an observed value is collected. We believe it is more reasonable to assume the observed value should fall within this window of simulated values than to assume it will match up with the daily average values presented in the previous figure. The five-day window of simulated values surrounding each observed DEQ sample is presented graphically in Figure 5.16;

the window surrounding each observed BSE sample is presented graphically in Figure 5.17.

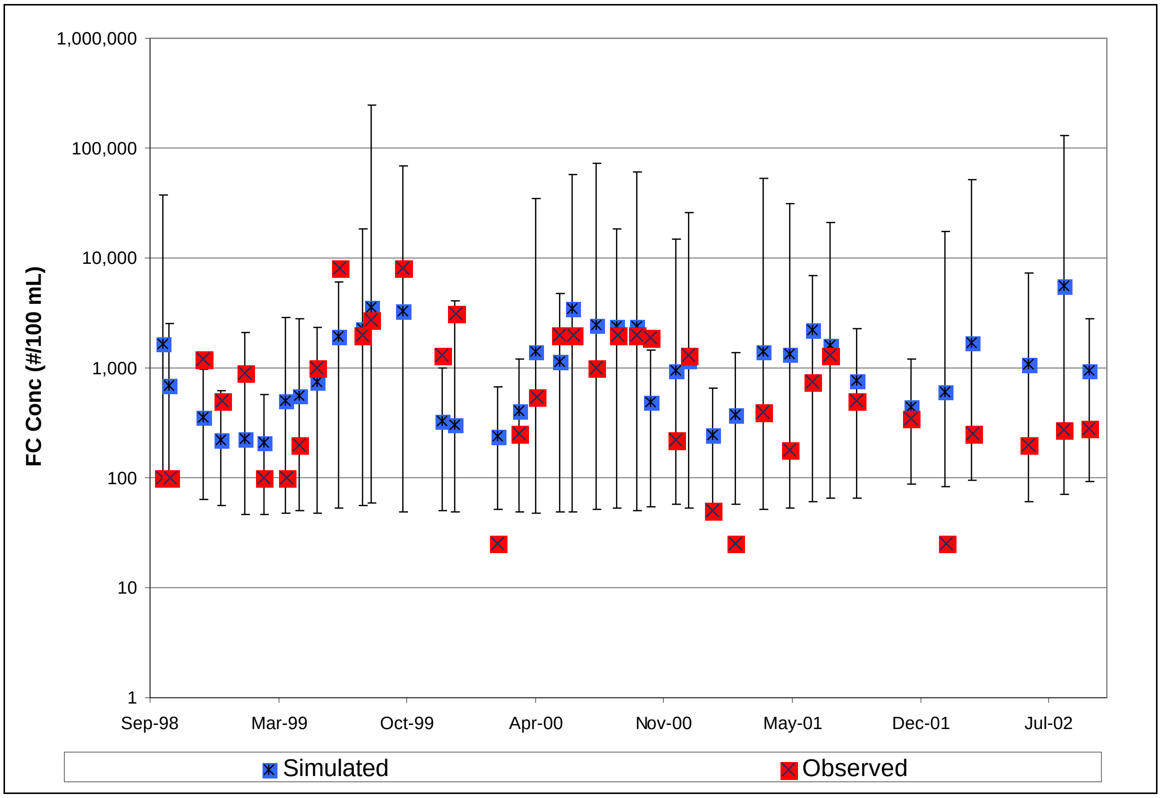

Figure 5.16. 'Five-Day Window' of Simulated Values Surrounding Each Observed DEQ Sample.

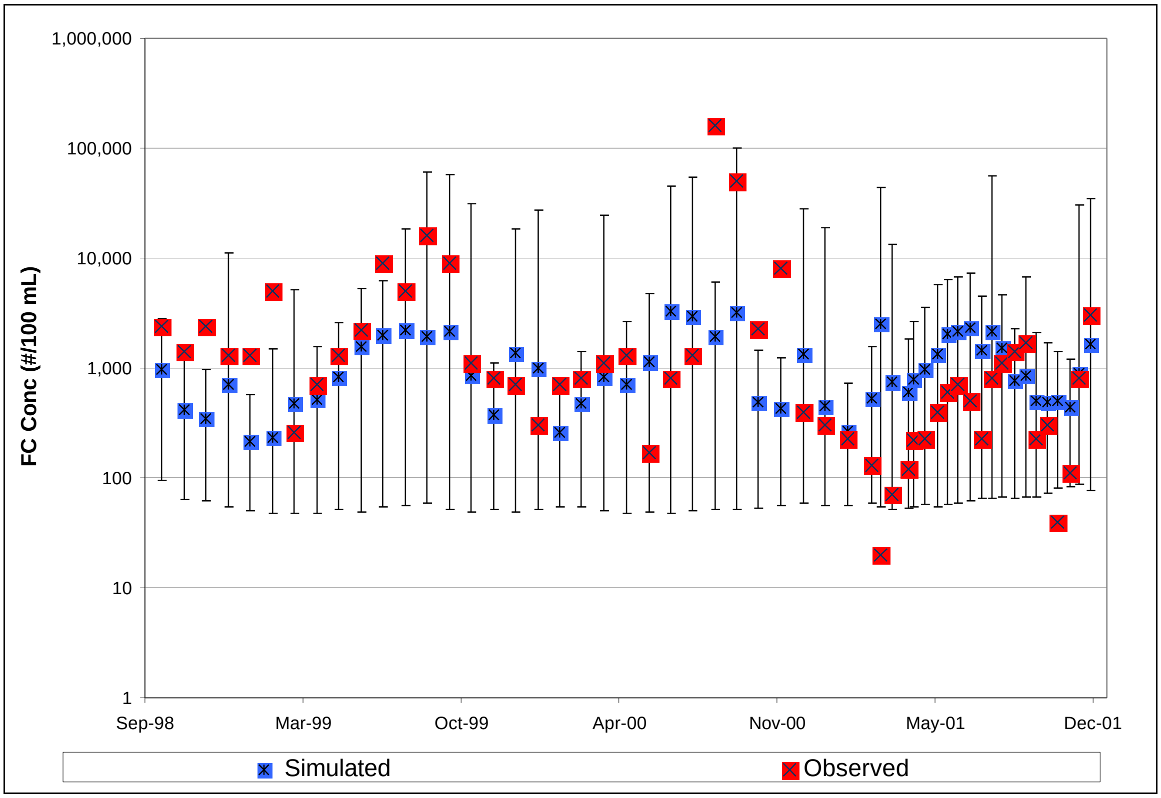

Figure 5.17. 'Five-Day Window' of Simulated Values Surrounding Each Observed BSE Sample.

The geometric mean of the simulated data for the calibration period is 761 cfu/100 mL; the geometric mean for the observed data for the same period at DEQ station is 442 cfu/100 mL. At the BSE station, the geometric mean of the observed data was 923 cfu/100 mL. Because the observed samples were collected on a monthly basis, a comparison of violations of the monthly geometric mean criterion cannot be conducted.

The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL is 73% for the simulated data for the water quality calibration period. The violation rate of the 400 cfu/100 mL standard was 53% for the observed DEQ data and 70% for the observed BSE data.

The final parameters used in the calibration and validation simulations are listed in Table 5.17.

Table 5.17. Final calibrated parameters for Mossy Creek.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)[c]
PERLND					
PWAT-PARM2					
FOREST	Fraction forest cover	none	1.0 forest, 0.0 other	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	3-6[a]	Soil properties	1
INFILT	Index to infiltration capacity	in/hr	0.75 forest, 0.02 loafing lot, 0.50 other	Soil and cover conditions	
LSUR	Length of overland flow	feet	238-246[a]	Topography	1
SLSUR	Slope of overland flowplane	none	0.02-0.04[a]	Topography	1
KVARY	Groundwater recession variable	1/in	0.0	Calibrate	
AGWRC	Base groundwater recession	none	0.99	Calibrate	
PWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.1	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0	Marsh/wetlands ET	
PWAT-PARM4					
CEPSC	Interception storage capacity	inches	monthly[b]	Vegetation	2
UZSN	Upper zone nominal soil moisture storage	inches	monthly[b]	Soil properties	3
NSUR	Mannings' n (roughness)	none	0.15-0.45[a]	Land use, surface condition	1
INTFW	Interflow/surface runoff partition parameter	none	0.5	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.99	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[b]	Vegetation	4

[a]Varies with land use
[b]Varies by month and with land use
[c]Tables located in Appendix E

Table 5.17. Final calibrated parameters for Mossy Creek.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)
QUAL-INPUT					
SQO	Initial storage of constituent	#/ac	$1x10^{10}$	Land use	
POTFW	Washoff potency factor	#/ton	0		
POTFS	Scour potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	monthly[b]	Land use	5
SQOLIM	Maximum accumulation of constituent	#	9 x ACQOP[b]	Land use	6
WSQOP	Wash-off rate	in/hr	2.5	Land use	
IOQC	Constituent conc. in interflow	#/ft3	8496	Land use	
PERLND					
AOQC	Constituent conc. in active groundwater	#/ft3	5664	Land use	
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	250	Topography	
SLSUR	Slope of overland flowplane	none	0.18	Topography	
NSUR	Mannings' n (roughness)	none	0.1	Land use, surface condition	
RETSC	Retention/interception storage capacity	inches	0.125	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
IQUAL					
SQO	Initial storage of constituent	#/ac	$1x10^{7}$		
POTFW	Washoff potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	$1x10^{7}$	Land use	
SQOLIM	Maximum accumulation of constituent	#	$3x10^{7}$	Land use	
WSQOP	Wash-off rate	in/hr	1.5	Land use	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.3		
GQUAL					
FSTDEC	First order decay rate of the constituent	1/day	2.30		
THFST	Temperature correction coeff. for FSTDEC		1.05		

[a]Varies with land use
[b]Varies by month and with land use
[c]Tables located in Appendix E

5.6.2. Long Glade Run

5.6.2.a. Hydrology

For the hydrologic component of the HSPF calibration, observed values for daily stream flow are required. Flow data from the Biological Systems Engineering monitoring station, QLA, located in Rockingham County near the border of Augusta County and Route 42 (Figure 3.2) were used to calibrate HSPF. The drainage area monitored at the station is 14.5 square miles (9269 acres) and the current available period of record is June 1998 through December 2002 (approximately 4 1/2 years). The output from the HSPF model for the hydrology calibration was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range.

The hydrologic calibration period was September 1, 1999 to July 31, 2000. There was insufficient data to perform a hydrologic validation. This conclusion was drawn from an analysis of the drought conditions surrounding the period of observed flow data at QLA. September 1, 1999 – August 30, 2000 was the longest period of non-drought weather experienced during the monitored period. The month of August was eliminated from the calibration period due to suspected faulty observed values. The months of available streamflow data were classified into the drought-wet spell categories according to the Palmer Drought Severity Index (Palmer, 1965). As shown numerically in Table 5.18 and graphically in Figure 5.18, over 75% of these months received less than normal precipitation. Attempts to calibrate the hydrologic model using streamflow data collected during periods of drought were unsuccessful. The calibration period was therefore selected as the longest consecutive period of time that the months fell within the incipient drought to incipient wet spell categories. Through this analysis, the calibration period selected was September 1999 through July 2000 (11 months). Due to this shortage of usable hydrologic data, no validation period was available. It is important to note that while Mossy Creek is adjacent to Long

Glade, the flow in Mossy Creek was not as severely impacted by the drought because it has numerous spring flow inputs.

Table 5.18. Drought/Wet Spell classification of available months of streamflow data for Long Glade Run.

Classification	Number of months	Months at or Drier than this Class
Extreme Drought	13	24.53%
Moderate Drought	9	41.51%
Mild Drought	12	64.15%
Incipient Drought	6	75.47%
Normal	6	86.79%
Incipient Wet Spell	2	90.57%
Mild Wet Spell	4	98.11%
Moderate Wet Spell	1	100.00%
Extreme Wet Spell	0	100.00%

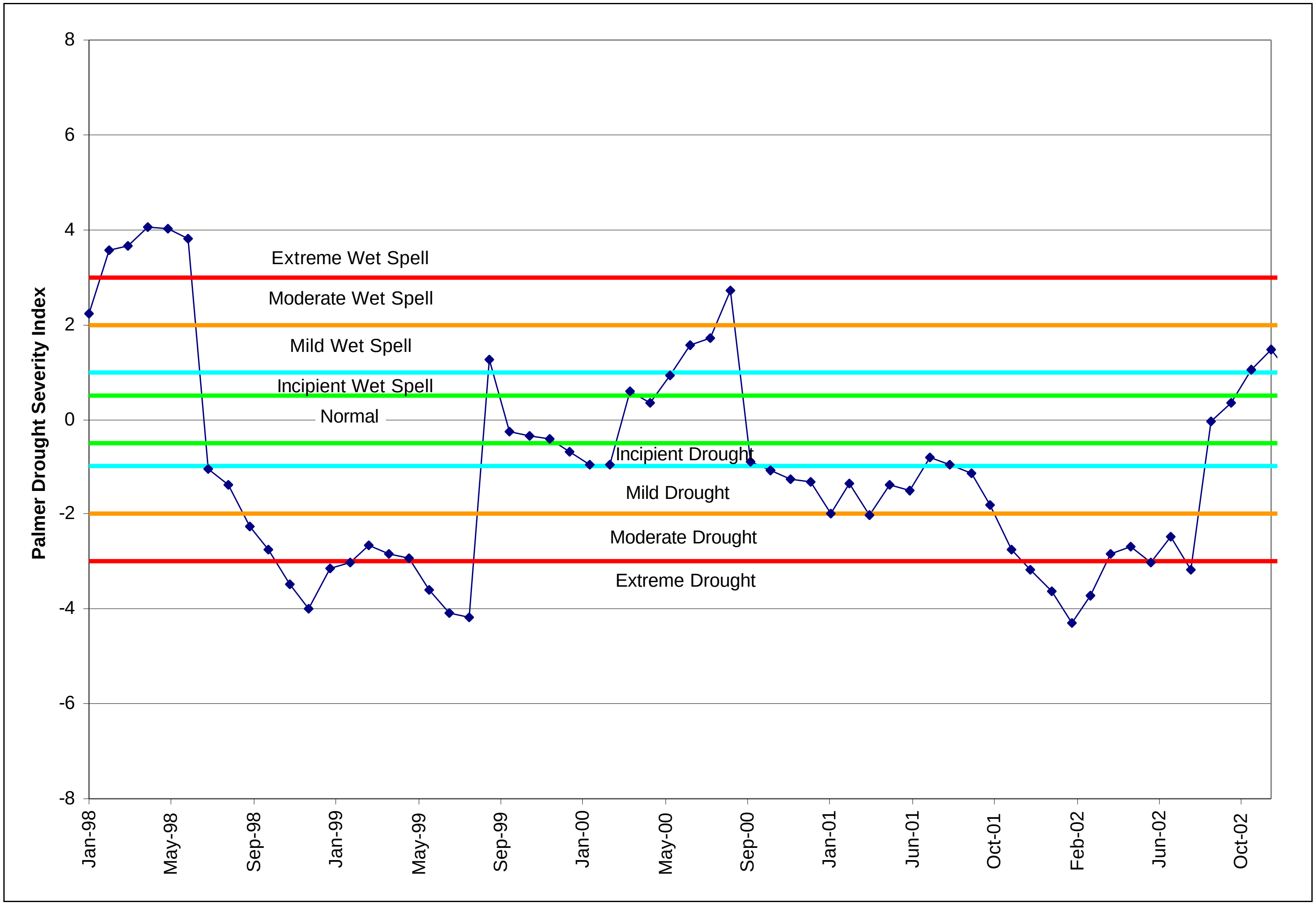

Figure 5.18. Palmer Drought Severity Index Analysis for the Long Glade Run Watershed.

The HSPEXP decision support system developed by USGS was used to calibrate the hydrologic portion of HSPF for Long Glade. Most of the default HSPEXP criteria for evaluating the accuracy of the flow simulation were used in the calibration for Long Glade. One criterion was relaxed, the seasonal volume parameter, from 10% to 15%, due to the extremely low flows during summer months that created high error percentages even when the absolute error was negligible. The criteria used in the Long Glade calibration are listed in Table 5.19. After calibration, all criteria listed in Table 5.19 were met.

Table 5.19. Criteria for HSPEXP used in the Long Glade Calibration.

Variable	Percent Error
Total Volume	10%
50 % Lowest Flows	10%
10 % Highest Flows	15%
Storm Peaks	15%
Seasonal Volume Error	15%
Summer Storm Volume Error	15%

The simulated flow for the calibration period matched the observed flow, as shown in Figure 5.19. The agreement with observed flows is further illustrated in Figure 5.20 for a representative storm.

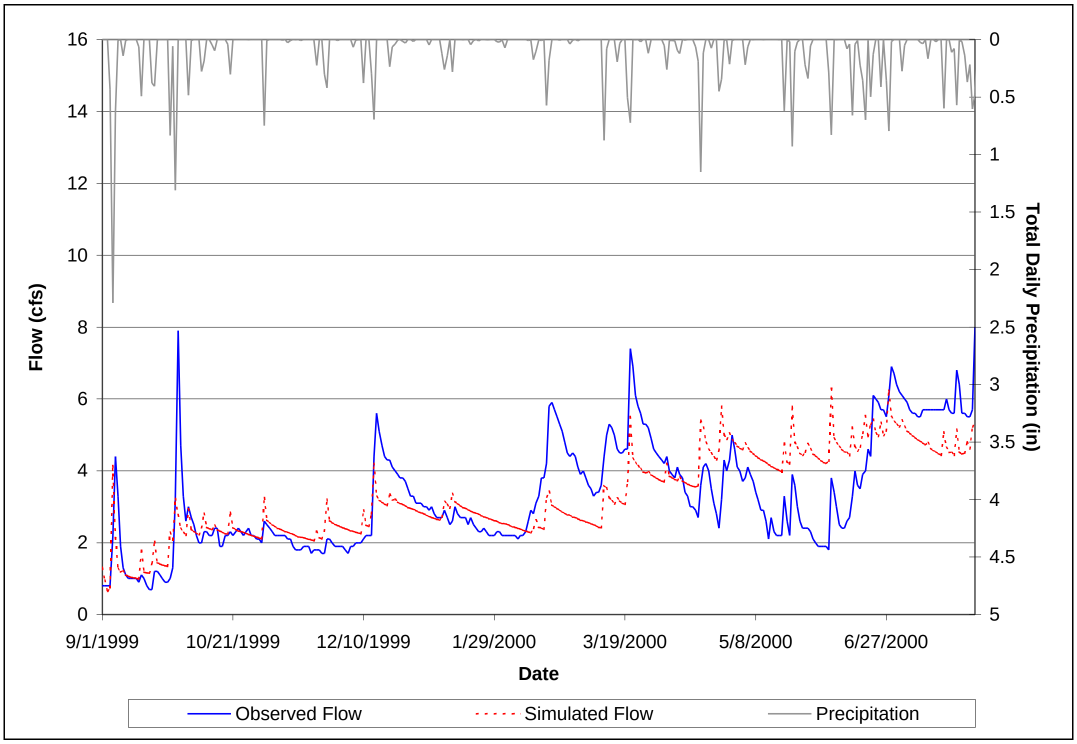

Figure 5.19. Observed and simulated flows and precipitation for Long Glade for the calibration period.

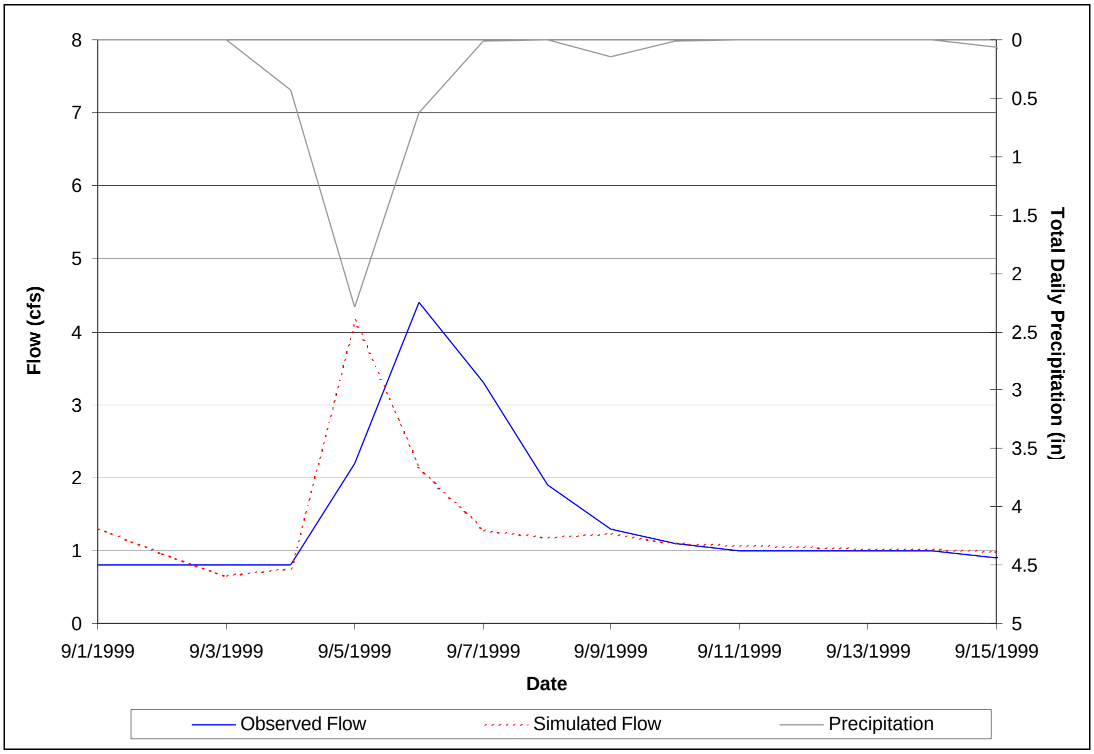

Figure 5.20. Observed and simulated flows and precipitation for Long Glade for a representative storm in the calibration period.

Although there was divergence between the simulated and observed flow during the period of May-June of 2000 (see Figure 5.19), the general flow response of the model was very good when comparing the cumulative frequency curse of the simulated and observed flow. The agreement between the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figure 5.21).

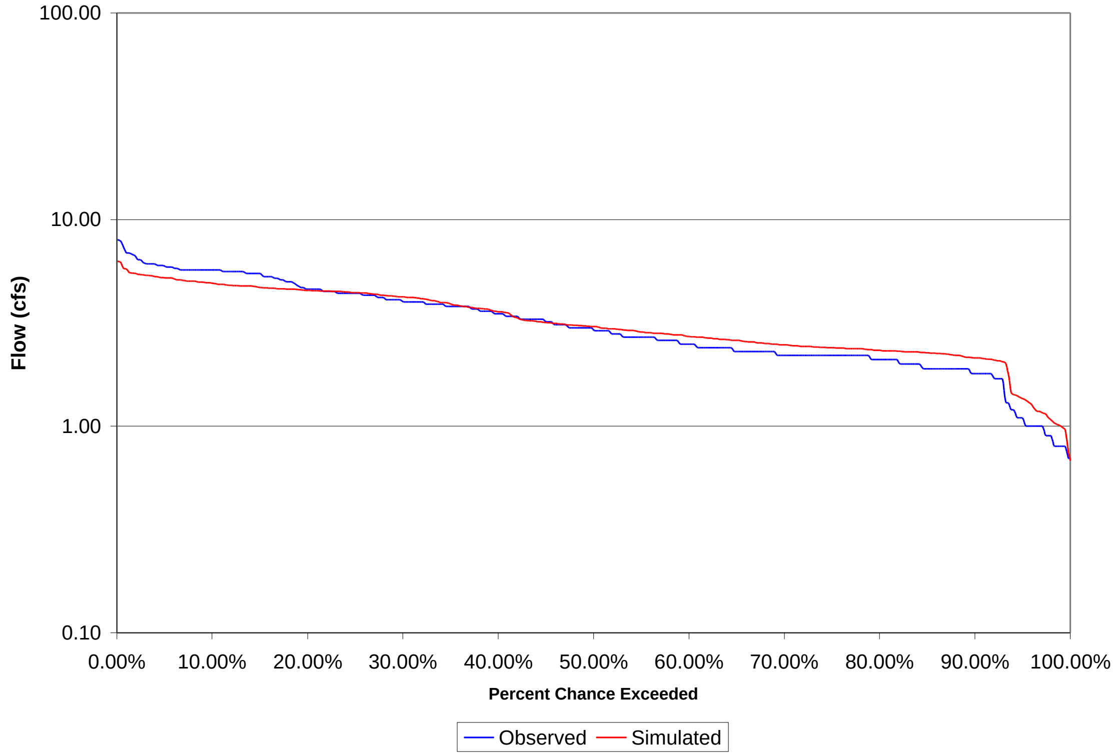

Figure 5.21. Cumulative Frequency Curve for Long Glade for the Calibration Period

As was previously mentioned, the expert system HSPEXP was used to assist with calibrating the Long Glade hydrologic model. Selected diagnostic output from the program is listed in Table 5.20. The total winter runoff and total summer runoff errors are considered in the HSPEXP term 'seasonal volume error' (see Table 5.19). The error for seasonal volume was 10.8% for the calibration period, within the ± 15% range we required.

Table 5.20. Summary statistics for the calibration period for Long Glade.

	Simulated	Observed	Error (%)	Criterion
Total Runoff	2.81	2.86	-2	10%
Total of Highest 10% of flows	0.45	0.522	+9	15%
Total of Lowest 50% of flows	0.98	0.898	-14	15%
Total Winter Runoff	0.64	0.729	-12	na
Total Summer Runoff	0.76	0.771	-1	na
Coefficient of Determination, r^2	0.45			

na = not applicable; these are not criteria directly considered by HSPEXP

Flow partitioning for the Long Glade hydrologic model calibration is shown in Table 5.21. When the observed flow data was evaluated using HYSEP, the baseflow index for the calibration period was 0.88. The short simulation period used does not leave much room for an overall representative average baseflow index; therefore, although the simulated baseflow index is much higher than observed, we feel it is adequate for this simulation. In addition, the unique drought conditions that surrounded the period of record may be influencing the baseflow index.

Table 5.21. Flow partitioning for the calibration and validation periods for Long Glade.

Annual Flow Type	Value for Calibration Period
Total Runoff (in)	2.81
Surface Runoff (in)	0.08 (3%)
Interflow (in)	0.04 (1%)
Baseflow (in)	2.69 (96%)
Baseflow Index	0.96

A list of final calibration parameters for both the hydrology and water quality simulations can be found at the end of the next section (Table 5.26).

5.6.2.b. Fecal coliform calibration

Direct Deposition of Manure at Very Low Flows

We modeled direct deposition of manure in streams by livestock considering stream depth. Fecal coliform inputs by livestock in streams are typically simulated without regard to stream depth. Under extremely low flow conditions, one animal defecating once in a stream reach can result in a violation of the instantaneous water quality standard; however, under such very low flows, it is not likely for animals to wade in or drink from the stream. Therefore, modeled direct deposition of manure by livestock at extremely low flow conditions can cause unrealistically high numbers of violations and make calibration difficult, and adversely affect the quality of the final calibration.

In order to more accurately model the water quality conditions at Long Glade, we used a stage (stream depth) of 1-inch as a cutoff for cattle direct deposition of manure. When the stream depth was less than 1 inch, direct deposition by cattle was set to zero; at stream depth values greater than 1 inch, direct deposition was left unchanged. In order to test the validity of this assumption, HSPF was run with the original direct deposit inputs and with the 1-inch stage cutoff direct deposit values using calibrated values for water quality parameters. Values for the instantaneous violations and geometric means of the simulated data as compared with the data observed at the VADEQ monitoring station are given in Table 5.22. The simulated values using the 1-inch stage cutoff for direct deposition were closer in value to the observed data than the simulated values that had no cutoff. This is expected, as direct deposition of manure at very low flows can cause a larger number of violations.

Table 5.22. Simulated and Observed Water Quality Characteristics

	Geometric Mean	Instantaneous Violations
Observed	626	60%
Simulated with 1 in cutoff	1148	100%
Simulated without cutoff	4243	100%

To be completely accurate, the fecal coliform direct deposit loading removed as a result of the cutoff should be reapplied to the pasture area (cattle not wading and defecating in the stream will have to graze and defecate on the pasture). For the purpose of modeling, if the fecal coliform loading removed by the 1-inch cutoff was greater than 1% of the total pasture-applied fecal coliform loading, it would be reapplied to the land in the model. Otherwise, this loading would simply be considered insignificant with respect to the loadings to the land. Table 5.23 compares the total cattle direct deposit fecal coliform loading for each reach with and without the 1-inch stage cutoff. The difference in these values was assumed to be the amount of fecal coliform 'lost' by imposing the cutoff. The amount of fecal coliform applied to pasture areas (through manure application, cattle deposits, and wildlife deposits) in each sub-watershed was calculated. If the amount of fecal coliform 'lost' was greater than 1% of the total pasture-applied fecal coliform loading, the 'lost' quantity of manure would be reapplied to pasture in the model. All the sub-watersheds in Long Glade Run had changes in fecal coliform loading much less than 1%. Also, the 'lost' fecal coliform numbers were so small compared to the loadings already being applied to the pasture that, were they added to the pasture loading in the ACCUM table, they would not change the number used in the ACCUM table given the significant figure limitation of the HSPF UCI file. Therefore, no manure had to be reapplied to the pasture areas.

Table 5.23. Details on 'Lost' Fecal Coliform for the Calibration Period

Reach	**Direct Deposit loading w/o cutoff**	**Direct Deposit loading w/ 1 inch cutoff**	**Difference in Direct Deposit loadings ('Lost' FC)**	**Pasture-Applied Fecal Coliform by Subwatershed**	**Percent 'Lost' FC is of Pasture-Applied FC**
1	2.23E+12	2.41E+10	2.21E+12	4.97E+15	0.04%
2	6.76E+12	5.20E+10	6.71E+12	3.91E+15	0.17%
3	1.91E+13	8.31E+12	1.08E+13	6.79E+15	0.16%
4	0.00E+00	0.00E+00	0.00E+00	1.33E+16	0.00%
5	5.54E+12	2.27E+12	3.27E+12	1.36E+15	0.24%
6	4.18E+13	1.70E+13	2.48E+13	2.45E+16	0.10%
7	3.58E+13	2.75E+13	8.34E+12	1.63E+16	0.05%
8	3.34E+13	1.76E+13	1.58E+13	1.75E+16	0.09%
9	0.00E+00	0.00E+00	0.00E+00	2.45E+16	0.00%

Using a 1-inch stage cutoff for manure deposition by cattle reduces the possibility of unrealistic instantaneous violations, resulting in a more accurate description of the fecal coliform concentration in the stream. Because this fecal coliform load was an insignificant portion of the total fecal coliform loading to pastures, there was no need to reapply the load to pasture lands within the watersheds. Consequently, the 1-inch stage cutoff method was used for the calibration and allocation scenarios for the Long Glade Run watershed.

Issues with Application of HSPF model to the Long Glade Run Watershed

It is commonly known, through our observations and anecdotal evidence from watershed stakeholders, that portions of Long Glade Run go dry during periods of drought. As previously mentioned, most of the period of hydrologic record occurred during drought or near-drought conditions. During simulation, the HSPF model accurately predicted that the stream depth would approach or equal zero at times. Unfortunately, after investigation, we discovered that HSPF outputs hourly values of -1.00E+30 for the fecal coliform concentration when the average depth in the reach approached zero. Therefore it was necessary to filter the output from the HSPF model using WDMUtil in order to remove these undefined numbers. A method was devised to set the undefined numbers (-1.00E+30) to 10 wherever they occurred. This value would prevent undefined conditions from occurring when calculating geometric mean (as would occur if the value was set to 0), while providing a reasonable number to use in daily average, maximum, and minimum calculations.

Long Glade Run Calibration using 1-inch Stage Direct Deposition Cutoff

The water quality calibration was performed at an hourly time step using the HSPF model. The water quality calibration period was September 1, 1999 through July 31, 2000. Output from the HSPF model was generated as an hourly timeseries of fecal coliform concentration. *E. coli* concentrations were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \quad [5.2]$$

The *E. coli* translator was implemented in the HSPF simulation using the GENER block. The geometric mean was calculated on a monthly basis. The final calibration parameters are shown in Table 5.26. The BST results for Long Glade are shown in Table 5.24 for the year 2001. Table 5.25 contains the simulated percent contributions from the major source categories to the instream load during the calibration period.

Table 5.24. Bacterial source tracking results at the Long Glade QLA station.

	ARA - Enterococci		
	Wildlife	Human	Livestock
Average	30%	27%	43%
Range	2-83%	0-65%	0-83%

Table 5.25. Simulated percent contributions from major source categories for Long Glade Run during the calibration period.

Scenario	Livestock DD	Livestock Land	Wildife DD	Wildlife Land	Septic Systems	Cats/ Dogs	Impervious	Interflow and Groundwater
Total period	22.53%	72.36%	0.01%	0.93%	0.01%	0.04%	4.10%	0.01%

DD = direct deposit

An obvious difficulty in comparing Table 5.24 and Table 5.25 is the difference in time. Table 5.24 contains BST results from the drought period, during which time the direct deposit contributions would be higher than normal (hence the contributions of up to 83% in the BST results from wildlife). Cattle direct deposit could also be exaggerated; however, due to the aforementioned fact that the stream will run dry in parts during periods of drought, cattle might need alternative water supplies, which could actually decrease the contributions found in the BST results as compared to a 'normal' precipitation year. Table 5.25 contains simulated data from the non-drought modeling period. Therefore, the results from the two tables cannot be reasonably compared. However, overall the simulated contributions from the various source categories fall within the range of observed BST data.

The simulated fecal coliform concentrations agree well with the observed fecal coliform concentrations. Figure 5.22 shows the daily average simulated fecal coliform concentrations and the observed data from the DEQ water quality station. The daily average simulated fecal coliform concentrations and the BSE station observed water quality data are given in Figure 5.23. At the DEQ sampling station the maximum observed concentration was a capped value of 8000 cfu/100 mL and the overall maximum simulated concentration at this point was 46,600 cfu/100 mL. At the BSE sampling station the maximum observed concentration was 3000 cfu/100 mL and the overall maximum simulated concentration at this point was 67,600 cfu/100 mL.

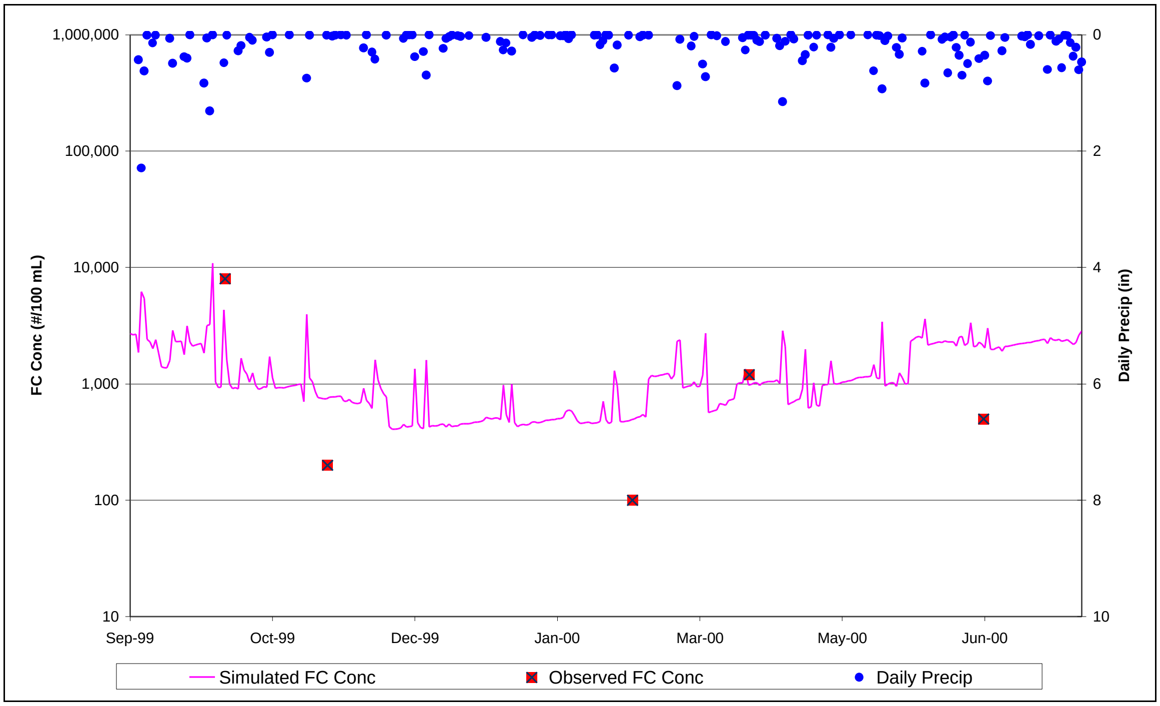

Figure 5.22. Observed and Simulated Fecal Coliform Concentrations at the DEQ Monitoring Station for the Water Quality Calibration Period.

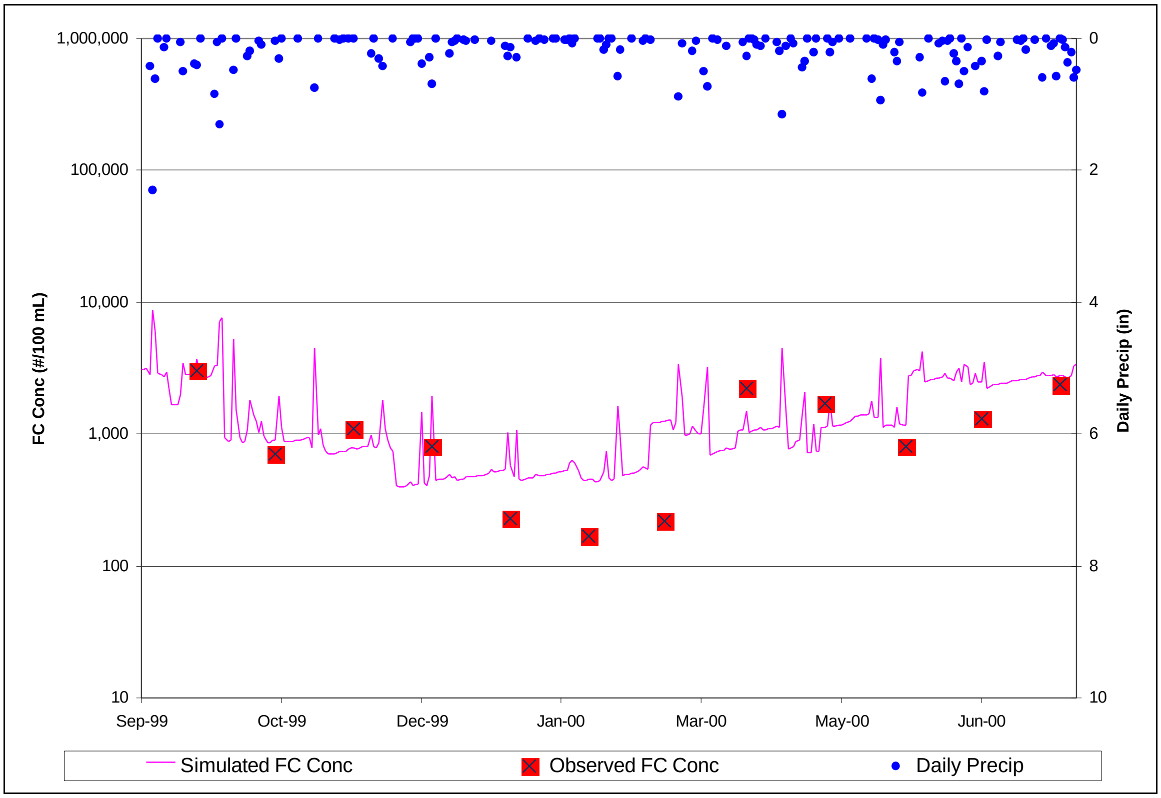

Figure 5.23. Observed and Simulated Fecal Coliform Concentrations at the BSE Monitoring Station for the Water Quality Calibration Period.

As described in Section 5.6.1.b for Mossy Creek, a five-day window was used in the Long Glade Run water quality calibration. The five-day window of simulated values surrounding each observed DEQ sample is presented graphically in Figure 5.24; the window surrounding each observed BSE sample is presented graphically in Figure 5.25.

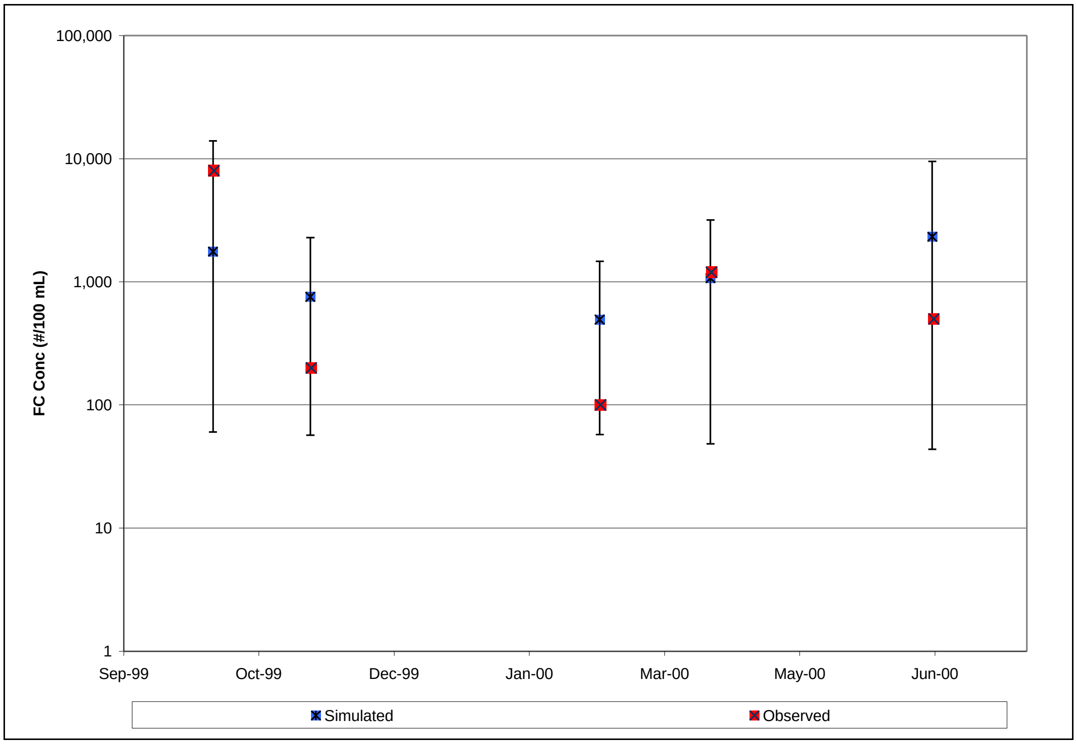

Figure 5.24. Five-Day Range of Simulated Fecal Coliform Values Surrounding Each Observed DEQ Sample.

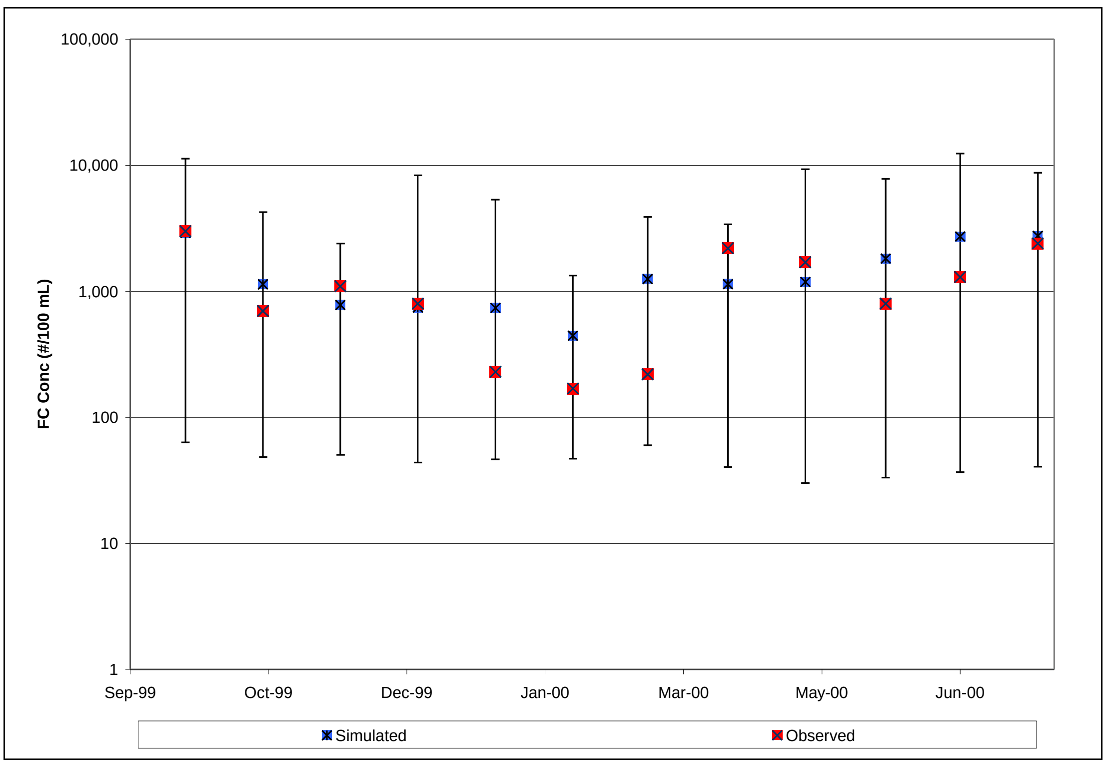

Figure 5.25. Five-Day Range of Simulated Fecal Coliform Values Surrounding Each Observed BSE Sample.

The geometric mean for the simulated data at the DEQ station for the entire calibration period is 1048 cfu/100 mL; the geometric mean for the observed data for the same period at this station is 626 cfu/100 mL. At the BSE station, the geometric mean of the simulated data was 1148 cfu/100 mL and the geometric mean of the observed data was 853 cfu/100 mL. Because the observed samples were collected on a monthly basis, a comparison of violations of the monthly geometric mean criterion cannot be conducted.

The violation rate of the instantaneous interim fecal coliform water quality standard of 400 cfu/100 mL is 60% for the observed DEQ data and 100% for the DEQ station simulated data. For the observed BSE data, the violation rate of the 400 cfu/100 mL standard was 75%, and the violation rate simulated for this station was 100%.

The final parameters used in the calibration and validation simulations are listed in Table 5.26.

Table 5.26. Final calibrated parameters for Long Glade Run.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)[c]
PERLND					
PWAT-PARM2					
FOREST	Fraction forest cover	none	1.0 forest, 0.0 other	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	7.15-10.15	Soil properties	7
INFILT	Index to infiltration capacity	in/hr	0.08-0.18[a]	Soil and cover conditions	7
LSUR	Length of overland flow	feet	238-246[a]	Topography	7
SLSUR	Slope of overland flowplane	none	0.074-0.099	Topography	7
KVARY	Groundwater recession variable	1/in	0.0	Calibrate	
AGWRC	Base groundwater recession	none	0.94-0.99	Calibrate	7
PWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.5	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0	Marsh/wetlands ET	
PWAT-PARM4					
CEPSC	Interception storage capacity	inches	monthly[b]	Vegetation	8
UZSN	Upper zone nominal soil moisture storage	inches	1.8[b]	Soil properties	
NSUR	Mannings' n (roughness)	none	0.15-0.45[a]	Land use, surface condition	1
INTFW	Interflow/surface runoff partition parameter	none	1.3 forest, 1.0 loafing lot, 1.1 other	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.70 forest, 0.63 other	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[b]	Vegetation	9

[a]Varies with land use
[b]Varies by month and with land use
[c]Tables located in Appendix E

Table 5.26. Final calibrated parameters for Long Glade Run.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix Table (if applicable)
QUAL-INPUT					
SQO	Initial storage of constituent	#/ac	0.5 x Average SQOLIM	Land use	
POTFW	Washoff potency factor	#/ton	0		
POTFS	Scour potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	monthly[b]	Land use	10
SQOLIM	Maximum accumulation of constituent	#	9 x ACQOP	Land use	11
WSQOP	Wash-off rate	in/hr	2.5	Land use	
IOQC	Constituent conc. in interflow	#/ft3	8496	Land use	
AOQC	Constituent conc. in active groundwater	#/ft3	5664	Land use	
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	300	Topography	
SLSUR	Slope of overland flowplane	none	0.07	Topography	
NSUR	Mannings' n (roughness)	none	0.05	Land use, surface condition	
RETSC	Retention/interception storage capacity	inches	0.065	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
IQUAL					
SQO	Initial storage of constituent	#/ac	$1x10^7$		
POTFW	Washoff potency factor	#/ton	0		
ACQOP	Rate of accumulation of constituent	#/day	$1x10^7$	Land use	
SQOLIM	Maximum accumulation of constituent	#	$3x10^7$	Land use	
WSQOP	Wash-off rate	in/hr	5.0	Land use	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.5		
GQUAL					
FSTDEC	First order decay rate of the constituent	1/day	2.30		
THFST	Temperature correction coeff. for FSTDEC		1.05		

[a]Varies with land use
[b]Varies by month and with land use
[c]Tables located in Appendix E

CHAPTER 6: BENTHIC STRESSOR ANALYSIS

6.1. Introduction

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not implicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in EPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Mossy Creek. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from DEQ monitoring as well as monitoring by the Biological Systems Engineering Department at Virginia Tech provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Volunteer monitoring data, land use distribution, point source Discharge Monitoring Report data (DMR), and visual assessment of conditions in and along the stream corridor provided additional information to investigate specific potential stressors. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The candidate benthic stressors considered in the following sections are temperature, pH, sediment, organic matter, nutrients, stocked trout, and toxics, including ammonia.

The results of the stressor analysis are divided into the following three categories:

- Non-Stressors: Stressors with data indicating normal conditions, without violations of a governing standard, or without observable impacts usually associated with a specific stressor. These stressors were eliminated from the list of possible stressors.

- Possible Stressors: Stressors with data indicating possible links, but with inconclusive data, were considered to be possible stressors.
- Most Probable Stressor(s): Stressor(s) with the most consistent data linking it with the poorer benthic metrics, or the most plausible of the possible stressors. This stressor(s) was selected as the most probable stressor(s) and was used for TMDL development.

Although in theory, the TMDL reference watershed is not selected until after the stressor is identified, in fact this was somewhat of an iterative process for Mossy Creek. In some cases, a comparison between parameters for the impaired Mossy Creek and the TMDL reference watershed was used to assess strength of evidence. This was especially true for parameters without state water quality standards or known harmful thresholds. Therefore, references will be made in this chapter to the Upper Opequon Creek watershed as the TMDL reference watershed, even though the discussion of the selection process does not occur until the following chapter.

6.2. Eliminated Stressors

<u>Temperature</u>

Mossy Creek is classified as a Class V water in Virginia with a maximum temperature standard of 21°C. Many summertime monitored exceedences of this standard were evident in Mossy Creek in the DEQ data, as shown in Figure 6.1. The standard for Class V waters was established to protect trout stocked in these waters, and while these exceedences may affect the trout population, it is doubtful that these temperatures are putting stress on the benthic community. Previous benthic TMDLs in the state have been developed for streams with a Class IV rating with a temperature standard of 31°C. Since Mossy Creek is in the same ecoregion as these other Class IV streams, the benthic communities are expected to be similar and affected by temperature in similar ways. Since Mossy Creek experienced no temperatures greater than the Class IV standard of 31°C, temperature does not appear to be a stressor.

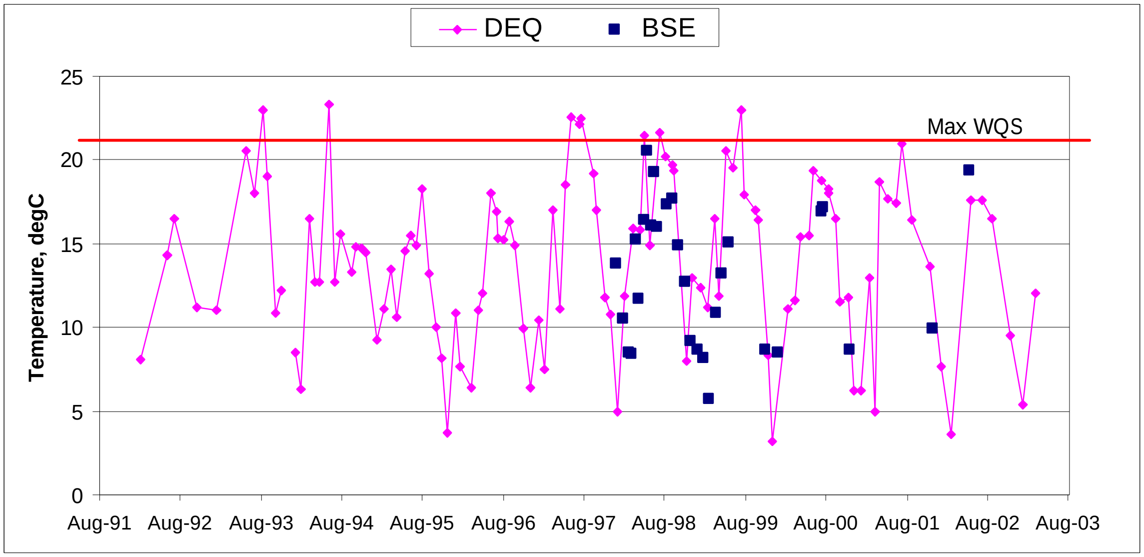

Figure 6.1. Water Temperature in Mossy Creek

<u>pH</u>

All field measurements of in-stream pH values fell within the standard limits of 6.0 – 9.0 for all classes of water in Virginia, as shown in Figure 6.2. Alkalinity concentrations also appear fairly constant, and most values lie within the normal range of 30 – 500 mg/L for groundwater in the Valley and Ridge physiographic region, as shown in Figure 6.3. Mossy Creek also exhibits less variability in alkalinity values than its TMDL reference watershed – the Upper Opequon Creek watershed. Therefore, pH was not considered to be a stressor.

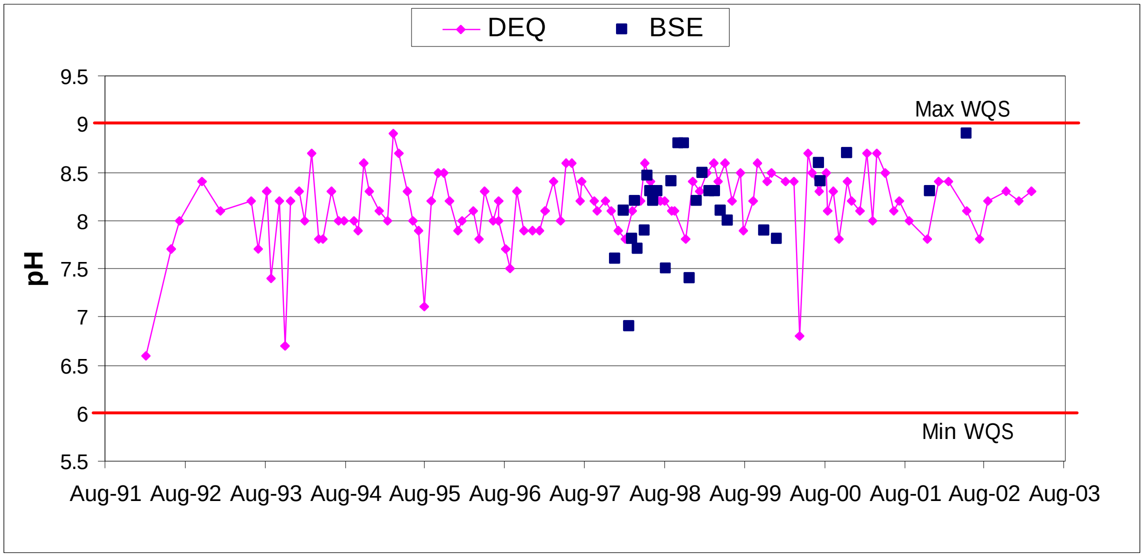

Figure 6.2. Field pH Data for Mossy Creek

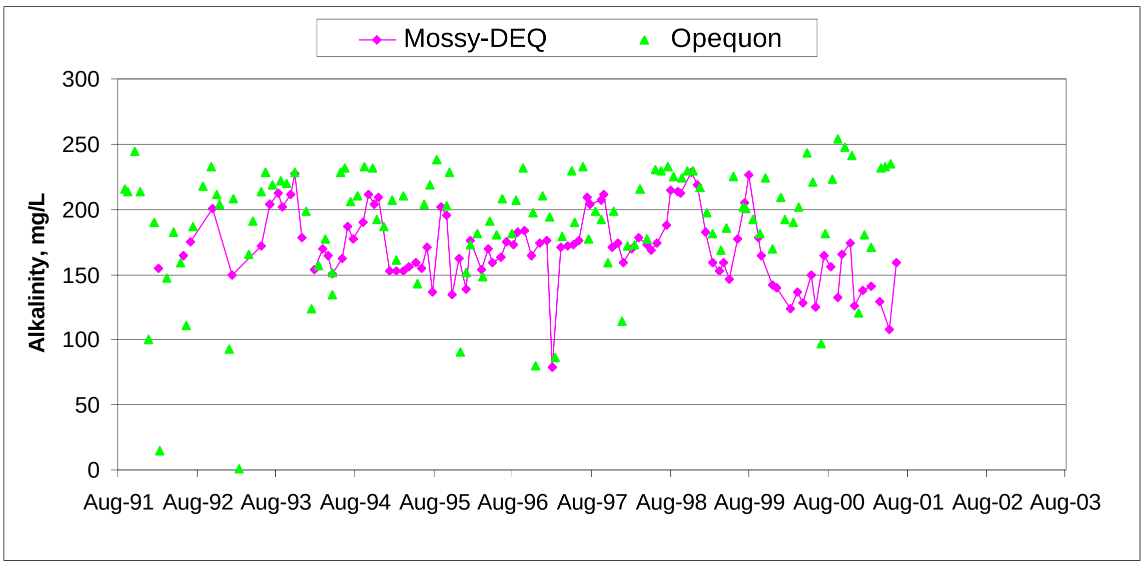

Figure 6.3. Alkalinity Concentrations in Mossy and Upper Opequon Creeks

<u>Toxics</u>

No permitted point source dischargers – potential sources of toxic inputs - reside in the Mossy Creek watershed. Chloride levels in Mossy Creek (Figure 6.4) are generally at or below the minimum detection level and substantially less than in its reference watershed, with no exceedences of the Chronic Aquatic Life

Criteria of 230 mg/L. No exceedences of the ammonia standard were reported in the DEQ data shown in Figure 6.5. The biological metrics also do not indicate a toxics problem: large numbers of total taxa and the presence of pollution-intolerant taxa further support the argument against toxic effects.

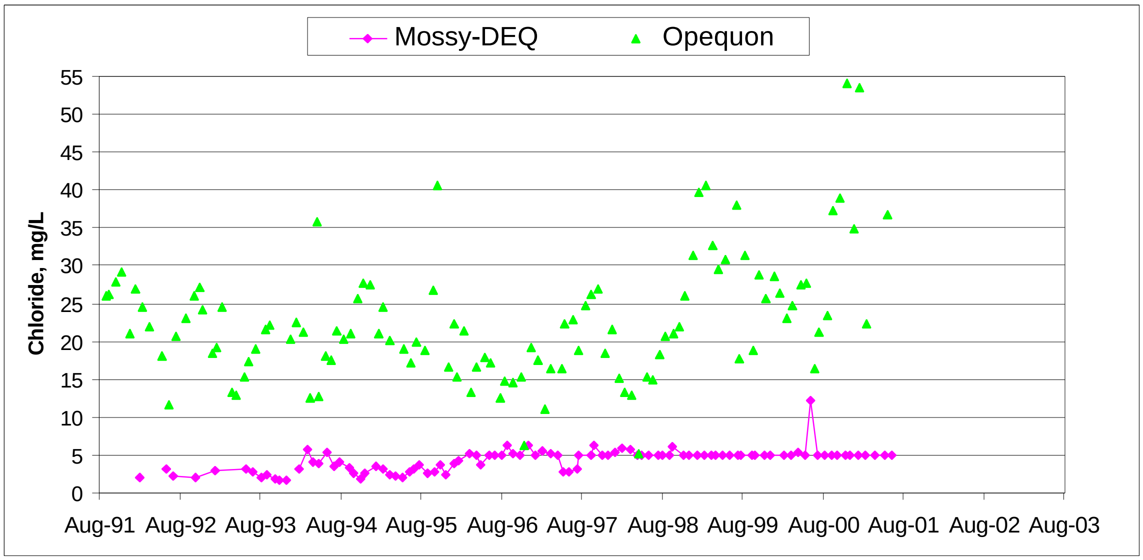

Figure 6.4. DEQ Chloride Concentrations in Mossy and Upper Opequon Creeks

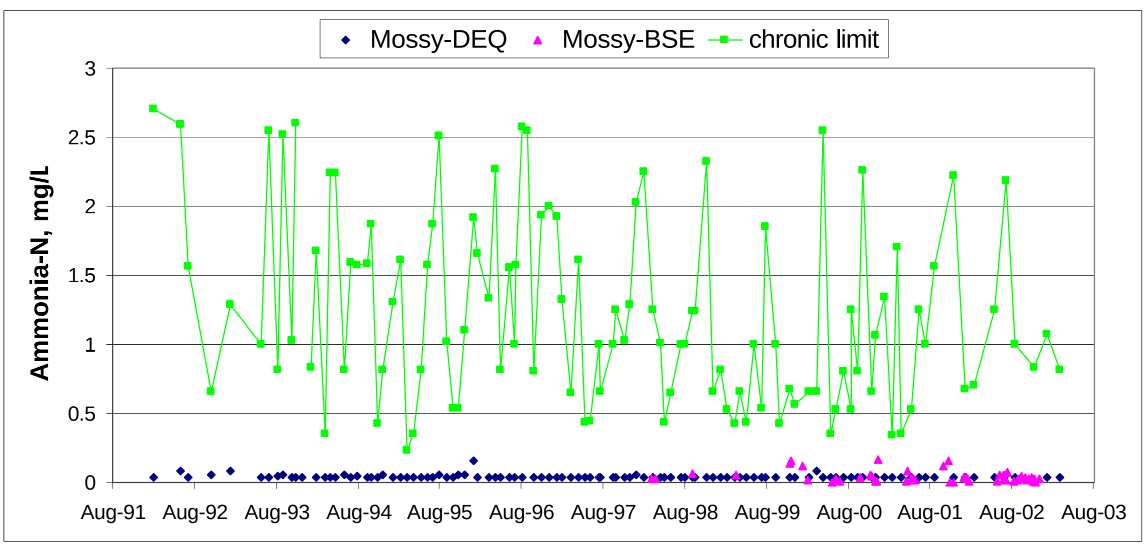

Figure 6.5. Ammonia-N Concentrations in Mossy Creek

Several periodic toxicity tests have been performed on sediment samples from the channel bottom in Mossy Creek (Table 6.1) without any values reported in excess of Consensus Probable Effect Concentration (PEC) levels, although many analyses were not performed using minimum detection limits (MDL) sufficient to compare with the PECs. Nevertheless, the remainder of the available evidence does not point to toxics as a stressor in Mossy Creek.

Table 6.1 Channel Sediment Toxicity Samples in Mossy Creek

1BMSS001.35 Mossy Creek

Parameter Description	6/18/92		7/22/96		8/31/00		Sediment PEC	Comments
ALDRIN, SEDIMENT (UG/KG DRY WT)	100	U			20	U		All values at MDL.
ALUMINUM, SEDIMENT (MG/KG AS AL DRY WGT)			13900		4080			
ANTIMONY, SEDIMENT (MG/KG AS SB DRY WGT)			5	U	5	U		MDL = 5
ARSENIC, SEDIMENT (MG/KG DRY WT)	7		9		5.2		**33**	
BERYLLIUM, SED (MG/KG AS BE DRY WT)	5	U	5	U	5	U		MDL = 5
CADMIUM, SEDIMENT (MG/KG DRY WT)	5	U	5	U	5	U	**4.98**	MDL = 5
CHLORDANE TECH MIX & METABS,SEDIMENT(UG/KG D	500	U			70	U	**17.6**	All values at MDL.
CHROMIUM, SEDIMENT (MG/KG DRY WT)	19		22		11.4		**111**	
COPPER, SEDIMENT (MG/KG AS CU DRY WT)	14		22		5	U	**149**	MDL = 5
DDD, SEDIMENT (UG/KG DRY WT)	100	U			40	U	**28**	All values at MDL.
DDE, SEDIMENT (UG/KG DRY WT)	100	U			40	U	**31.3**	All values at MDL.
DDT, SEDIMENT (UG/KG DRY WT)	100	U			40	U	**62.9**	All values at MDL.
DICOFOL (KELTHANE)	100	U			80	U		All values at MDL.
DIELDRIN, SEDIMENT (UG/KG DRY WT)	100	U			20	U	**61.8**	All values at MDL.
ENDRIN, SEDIMENT (UG/KG DRY WT)	100	U			50	U	**207**	All values at MDL.
HEPTACHLOR EPOXIDE, SED (UG/KG DRY WT)	100	U			20	U	**16**	All values at MDL.
HEPTACHLOR, SEDIMENT (UG/L)	0.1	K			20	U		All values at MDL, except 0.1 noted as "K".
IRON, SEDIMENT (MG/KG AS DRY WT)			20700		12600			
LEAD, SEDIMENT (MG/KG AS PB DRY WT)	19		21		11		**128**	
MANGENESE, SEDIMENT (MG/KG AS DRY WT)			586		558			
MERCURY, SEDIMENT (MG/KG AS HG DRY WT)	0.3	U	0.3	U	0.3	U	**1.06**	MDL = 0.3
NICKEL, SEDIMENT (MG/KG DRY WT)	12		16		5.2		**48.6**	
PCBS TOTAL,SEDIMENT (UG/KG DRY WT)	500	U			20	U	**676**	All values at MDL.
PENTACHLOROPHENOL, SEDIMENT (UG/KG DRY WT)	50	U			80	U		All values at MDL.
SELENIUM, SEDIMENT (MG/KG AS SE DRY WT)	1	U	1	U	1	U		MDL = 1
SILICA, DISS (MG/L AS SI 02)								2/92 - 1/93:5 values ranging from 6.52 to 9.15
SILVER, SEDIMENT (MG/KG AS AG DRY WT)	5	U	5	U	5	U		MDL = 5
THALLIUM, SEDIMENT (MG/KG DRY WT)	5	U	5	U	5	U		MDL = 5
TOXAPHENE, SEDIMENT (UG/L)	1	K			130	U		All values at MDL, except value of 1 noted as "K".
ZINC, SEDIMENT (MG/KG AS ZN DRY WT)	47		59		28.3		**459**	

U = analyzed, but not detected. Value is limit of detection.
PEC = probable effect concentration.
K = Off-scale low. Actual value not known, but known to be less than value shown.

<u>Stocked Trout</u>

Mossy Creek is a stocked trout stream, and as such, the trout represent a human-induced factor that could affect the structure and function of the benthic macroinvertebrate community. A 3-mile stretch of Mossy Creek from the mouth of Joseph Spring to the county line is stocked for public fishing by the Virginia Department of Game and Inland Fisheries. Trout are generally stocked in November as 6”-7” sub-catchable fish. The diet of smaller trout consists of terrestrial and aquatic invertebrates, switching to smaller fish as they mature. During trout fishing season, the minimum catch size limit is 20”. While spawning by the introduced trout is possible, it is considered rare, and restocking occurs on an annual basis. Pursuing this line of inquiry, several knowledgeable professionals were consulted in addition to the VDGIF fisheries biologists. Dr. Paul Angermeier, an Associate Professor in the Fisheries and Wildlife Department at Virginia Tech said that he was not aware of any research that would relate trout populations to benthic population impacts (personal communication, May 23, 2003). George Devlin, a Regional Biologist at VDEQ, said that he had not seen any trends in the RBP II or MAIS metrics that showed an impact from introduced fish. Young, small trout feed primarily on invertebrates in the drift, as they are not built for picking bugs off of the riffle substrate (personal communication, May 29, 2003). It is possible that most stocked trout are already near the size when they prefer fish to invertebrates for their diet. Also, since the number of trout stocked into a stream is usually relatively low compared to the number of native or naturally occurring fish, their impact on the benthic community was not deemed to be a significant stressor, and was eliminated from further consideration.

6.3. Possible Stressors

<u>Nutrients</u>

Ambient nitrate (dissolved nitrogen, Figure 6.6) and orthophosphate (dissolved phosphorus, Figure 6.7) concentrations in Mossy Creek were above those needed for eutrophication (eutrophic sufficiency levels are 0.3 mg/L for nitrogen and 0.01 mg/L for phosphorus), but considerably less than in its reference watershed. DEQ-monitored Total Phosphorus concentrations did not exceed their “threatened waters” threshold of 0.2 mg/L. There were several high values of Total Phosphorus monitored by BSE during storm runoff, but these were most likely comprised of the less biologically available, sediment-attached phosphorus. The ratio of nitrogen to phosphorus was 21:1, which indicated that phosphorus was the limiting nutrient. Mossy Creek received a medium total nitrogen (TOTN) rank in the VADCR 2002 Nonpoint Source Assessment. Although nutrient levels were slightly elevated and some algal growth was noted by volunteer monitors (Table 6.2), dissolved oxygen (DO) concentrations were all above the minimum water quality standard (Figure 6.8) and did not indicate stress on the benthic community. Nutrients are probably not a stressor.

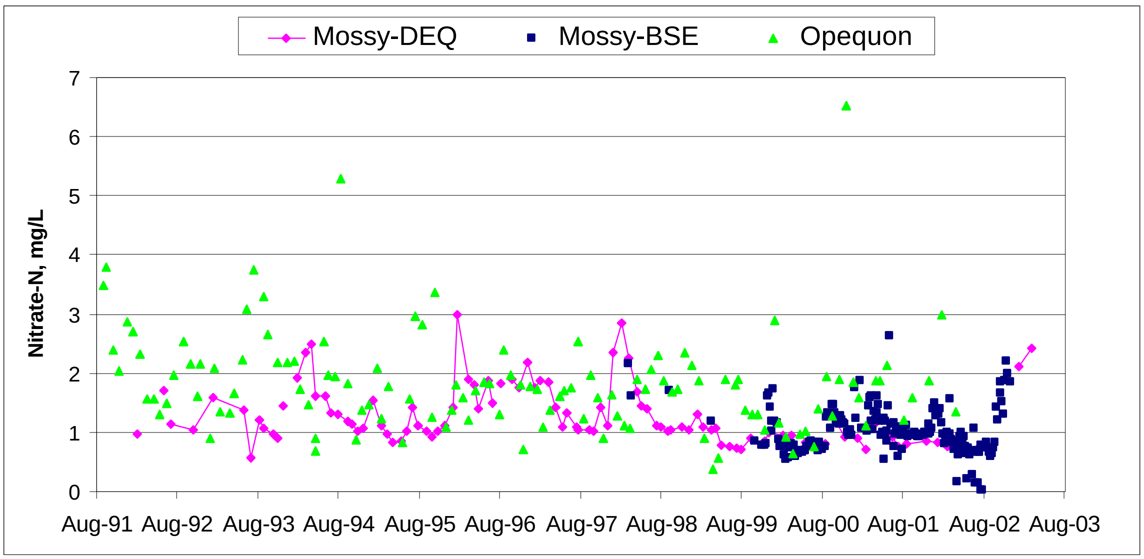

Figure 6.6. Nitrate-Nitrogen Concentrations in Mossy and Upper Opequon Creeks

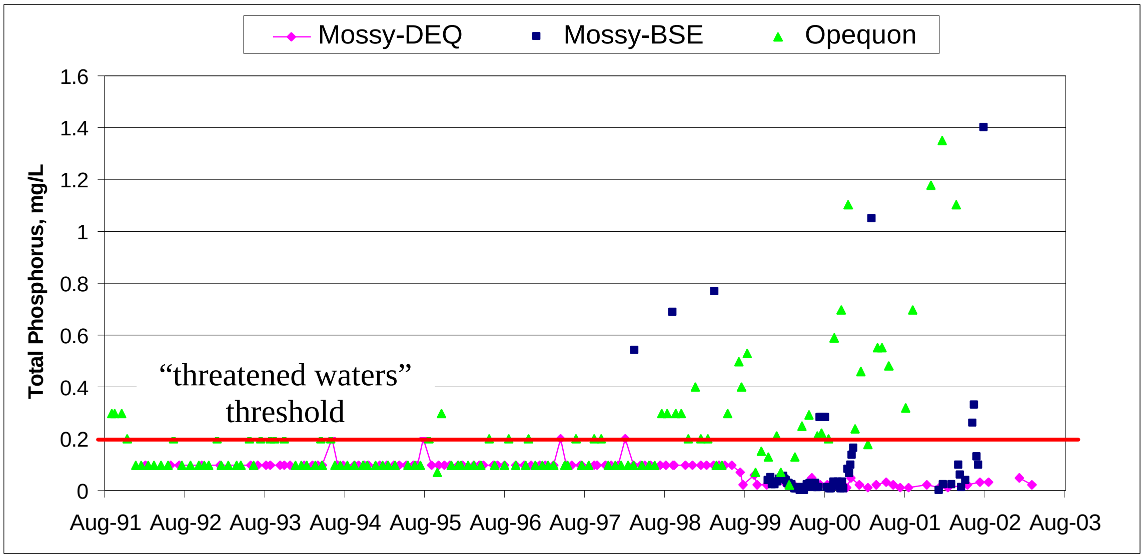

Figure 6.7 Total Phosphorus Concentrations in Mossy and Upper Opequon Creeks

Table 6.2. Citizen Monitoring Data on Mossy Creek

DEQ Station ID	1BMSS-1-SOS		Citizen's Monitoring Data		
Date	**4/19/98**	**7/17/98**	**10/24/98**	**1/16/99**	**5/29/99**
Stream Quality Score	20	16	22	26	20
Stream Quality Rating	Good	Fair	Good	Excellent	Good
% algae cover			60	0	
SB erosion	20	0	10	50	
% mud	0	2	0	10	
%sand	0	0	10	10	
%gravel	10	10	20	20	
%cobbles	40	40	30	50	
%boulders	50	50	40	10	
Flow rate	high	normal	low	normal	low

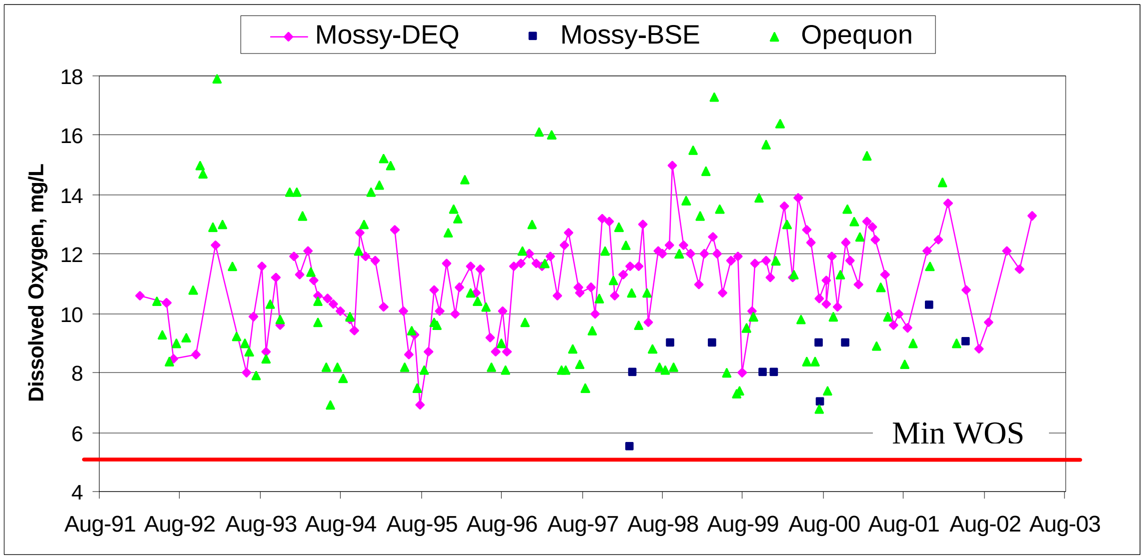

Figure 6.8. Dissolved Oxygen Concentrations in Mossy and Upper Opequon Creeks

<u>Organic Matter</u>

Several factors were monitored that, if elevated, might indicate a problem due to increased levels of organic matter. The available total organic carbon (TOC) measurements, shown in Figure 6.9, were all below the groundwater criteria of 10 mg/L and did not indicate organic enrichment. Concentrations of total Kjeldahl nitrogen (TKN) were low compared with nitrate-N measurements in Figure 6.10, indicating minor contributions from organic N. A combination of high volatile solids (VS) and high BOD tend to indicate elevated organics, however VS were a minor portion of the total dissolved solids, as shown in Figure 6.11, and most BOD_5 measurements (Figure 6.12) were at or below the minimum detection limit (MDL) of 2 mg/L (1 mg/L before October 1997). Likewise, chemical oxygen demand (COD) measurements after July 1994 (Figure 6.13) were predominantly at their minimum detection limit of 5 mg/L, and comparatively lower than in the reference watershed; and as mentioned previously, ambient dissolved oxygen concentrations are meeting the water quality standard.

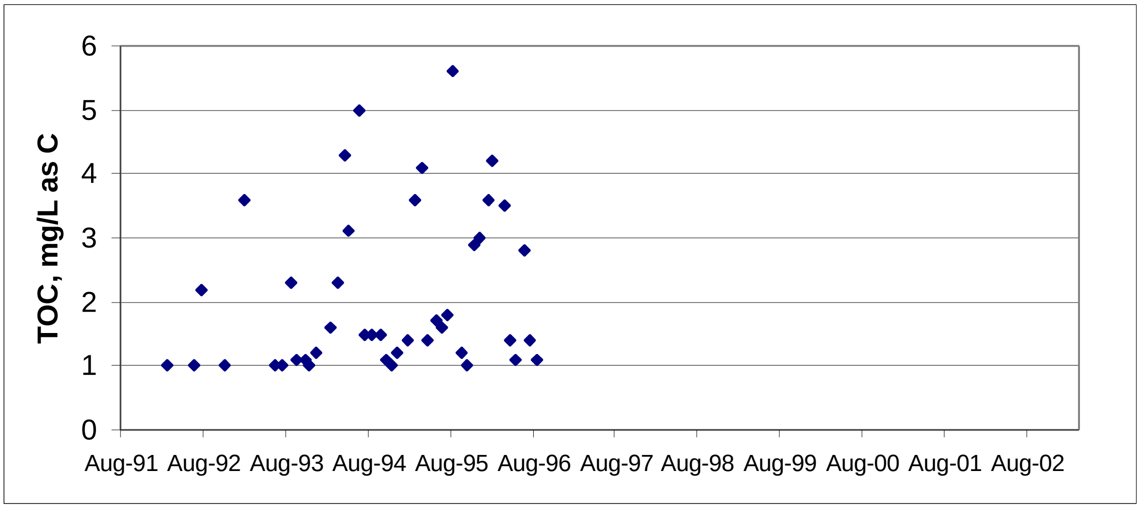

Figure 6.9. DEQ Total Organic Carbon Concentrations in Mossy Creek

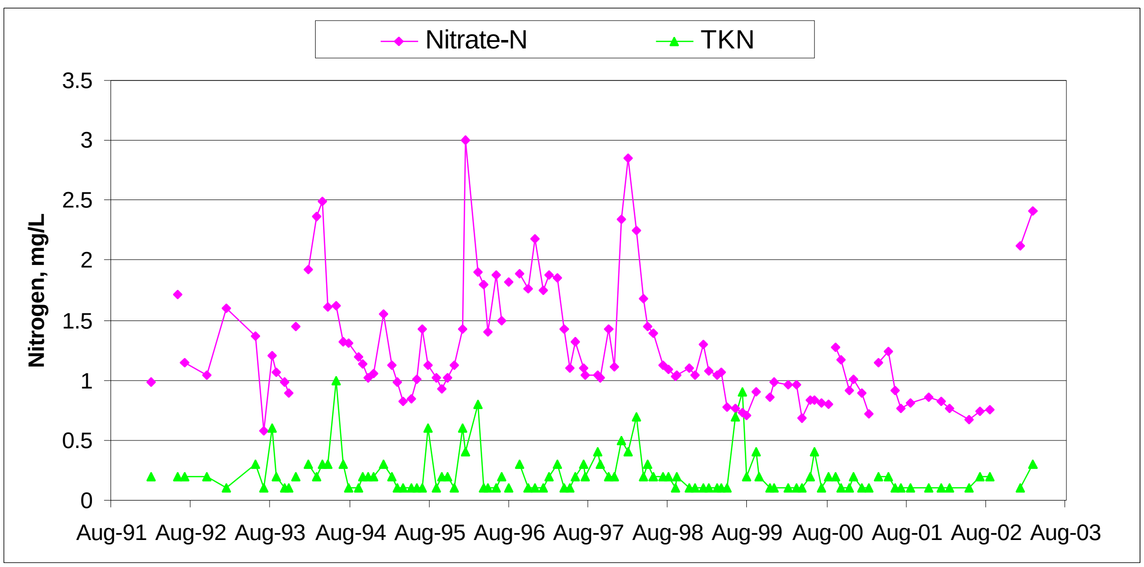

Figure 6.10. DEQ Nitrate-N and TKN Concentrations in Mossy Creek

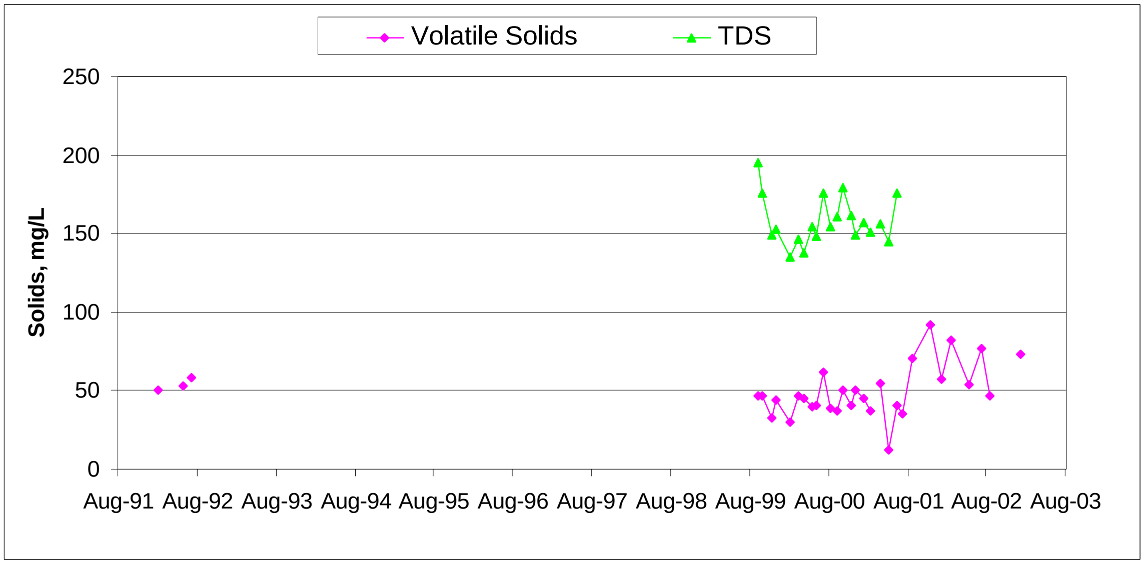

Figure 6.11. DEQ Volatile and Total Dissolved Solids in Mossy Creek

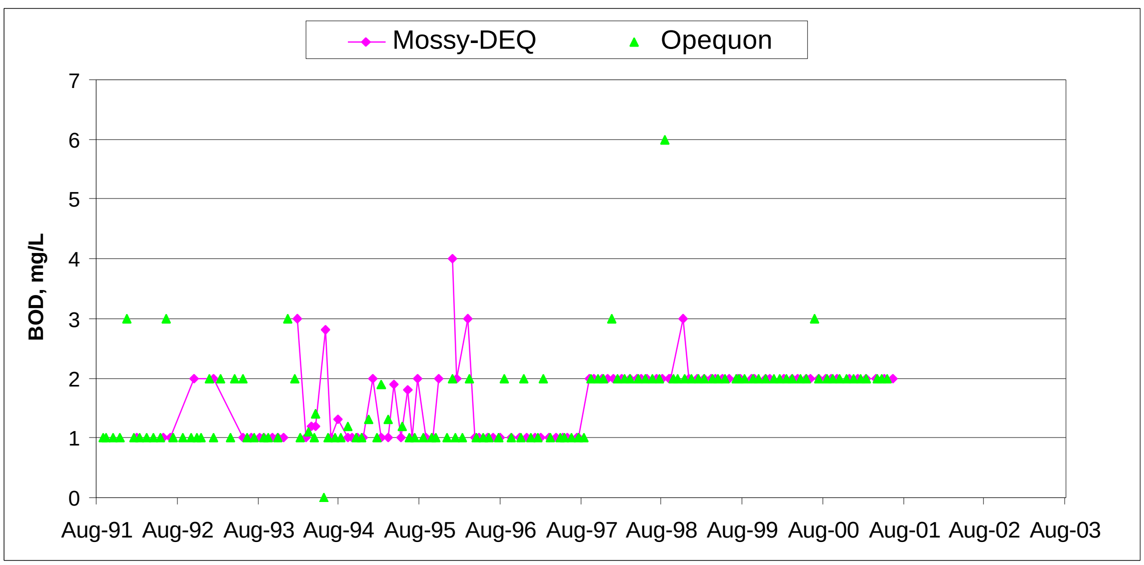

Figure 6.12. DEQ-monitored 5-day BOD in Mossy and Upper Opequon Creeks

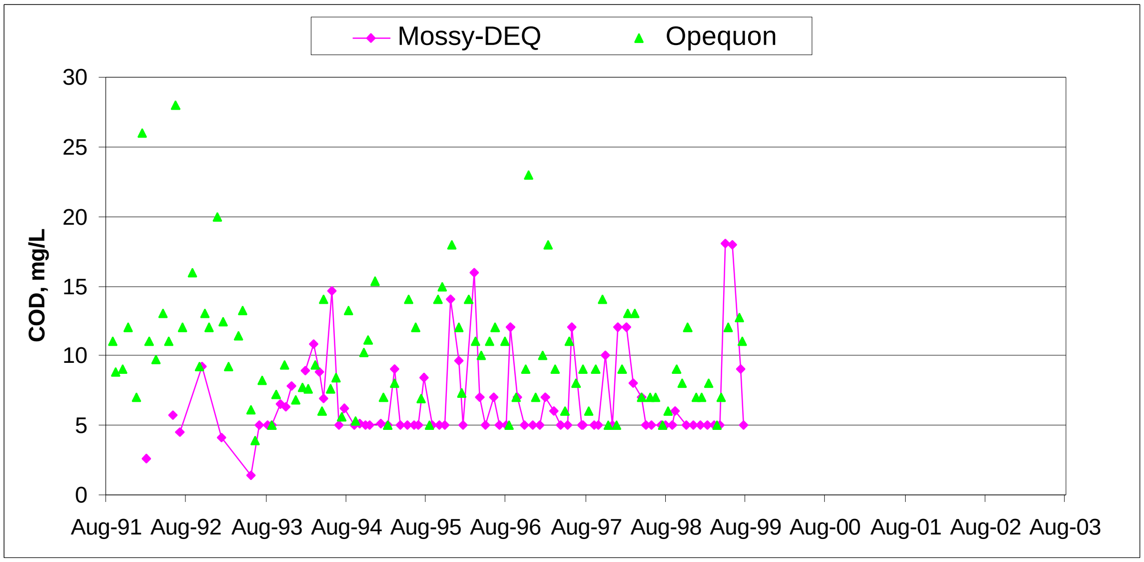

Figure 6.13. DEQ-monitored COD in Mossy and Upper Opequon Creeks

On the other hand, the *Hydropsychidae* species, which is a fairly reliable indicator of moderate levels of organic or nutrient pollution, was dominant in all but two of the macroinvertebrate samples. Furthermore, moderate values for the MFBI metric and the presence of *Asellidae* (though in low numbers) in all but one sample, also support the case for slightly elevated levels of organic inputs. The organic inputs did not originate as coarse particulate matter in the form of leaf litter, as the stream has little forested riparian cover, and the shredder functional group that processes CPOM was minimally present. In fact, the *Plecoptera* order, which contains many of the shredder species, has been totally absent in all samples. One possible source of additional organic inputs certainly could be manure from the large numbers of livestock in the watershed, many in riparian pastures, and many with direct stream access. Although the chemical analyses provide no evidence of organic pollution, the benthic metrics indicate that organic matter is a possible stressor.

Sediment

Volunteer monitoring data (Table 6.2) indicated increasing fines deposition at their monitoring site along with increasing stream bank erosion in 1999. Ambient concentrations of total suspended solids (Figure 6.14), although only one component of sediment, were generally higher in Mossy Creek than in its reference watershed, and storm runoff events monitored by BSE show evidence of even larger TSS concentrations. Ambient turbidity measurements monitored by DEQ (Figure 6.15) show a similar relationship to the TSS. Further evidence supporting sediment as a stressor comes from the sharp increase in embeddedness in the habitat evaluation that has occurred over the last 3 samples, as indicated by its decreasing metric score indicating increasing sedimentation (Table 3.6). The last sample was also evaluated as having increased development of sediment point bars in the stream, which together with the increasing embeddedness have negatively affected habitat conditions.

Although at first glance habitat appears to have dramatically improved, comparing the 1995-1997 period (used for the 1998 assessment) to the post-1988 period, this increase in habitat scores corresponded with a change in DEQ field monitors and probably did not represent an actual change, so the relationship between present habitat scores and those associated with the original impairment assessment is unknown. However, since the beginning of 1998, when the same monitor has been conducting the assessment, the assessments show a decline in the overall habitat score, with the decreasing trend directly linked to increases in channel alterations, embeddedness, and sediment point bar formation, all indicators or predictors of sediment impact. Sediment, whether or not responsible for the original impairment, is definitely stressing the benthic community at present.

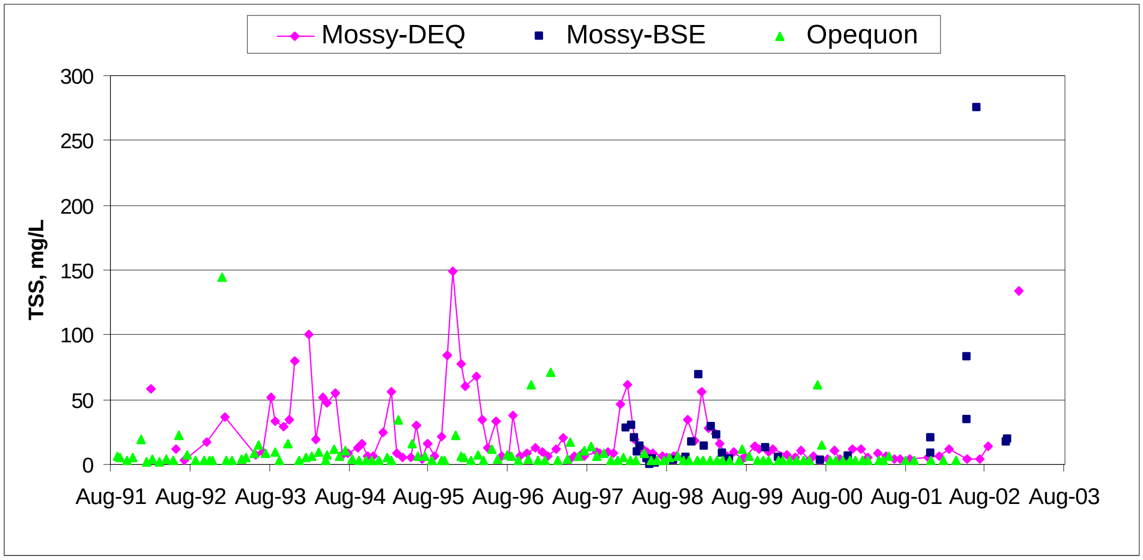

Figure 6.14. Total Suspended Solids Concentrations in Mossy and Upper Opequon Creeks

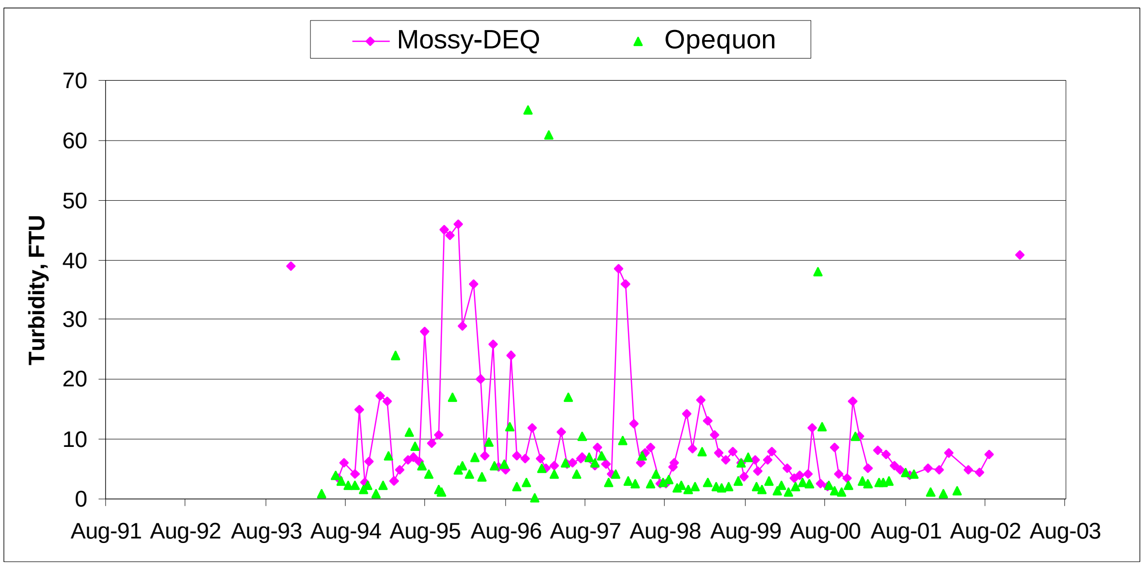

Figure 6.15. DEQ Turbidity in Mossy and Upper Opequon Creeks

6.4. Most Probable Stressor

After analyzing the available data for Mossy Creek watershed, no single unambiguous stressor emerged during the stressor analysis. After discussion with the regional DEQ TMDL coordinator and biologist, and state DEQ and DCR personnel, sediment was selected as the most probable stressor in Mossy Creek. Sediment was chosen based on the following rationale:

- Recent declining trends in habitat scores related to sediment – embeddedness, channel alterations, and in-stream sediment point bars, the larger TSS concentrations observed with runoff events, and streambank erosion related to livestock access, are all consistent with an impairment by sediment.

- Many best management practices (BMPs) employed to control sediment result in decreases in the other possible stressors (i.e., nutrients and organics) as well. Best management practices that might be used during implementation include those that would address the open canopy, streambank stability, riparian buffer zones, livestock access to the stream, and runoff from agricultural fields. Some examples of the synergistic reductions from sediment BMPs are:

    - Reducing livestock access to streams also reduces inputs of organic matter (manure) and nutrients

    - Stream buffers reduce overland flow velocities, thus decreasing sediment transport capacity and transport of sediment-attached nutrients, as well as reductions in suspended sediment and organic matter.

- The ultimate criteria for judging the success of the TMDL will be the restoration of the benthic community itself. As implementation proceeds, progress will be monitored, and the effectiveness of the implementation strategy will be evaluated.

In summary, it is the collective best professional judgment of the TMDL contractors and DEQ and DCR personnel that the Mossy Creek TMDL should be developed and implemented for sediment to address its benthic impairment.

CHAPTER 7: THE REFERENCE WATERSHED MODELING APPROACH

7.1. Introduction

Because Virginia has no numeric in-stream criteria for sediment, a "reference watershed" approach was used to set allowable sediment loading rates in the impaired watershed.

The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired. This reference watershed may be, but does not have to be, the watershed corresponding to the monitoring site used for determining comparative biological metric scores. The reference watershed is selected on the basis of similarity of land use, topographical, ecological, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment.

The reference watershed approach involves assessment of the impaired reach and its watershed, identification of potential causes of impairment through a benthic stressor analysis, selection of an appropriate reference watershed, model parameterization of the reference and TMDL watersheds, definition of the TMDL endpoint using modeled output from the reference watershed, and development of alternative TMDL reduction (allocation) scenarios.

7.2. Selection of Reference Watershed for Sediment

7.2.1. Comparison of Potential Watersheds

The initial list of potential reference watersheds was composed of Strait Creek (the watershed corresponding to the biological monitoring reference site for Mossy Creek), the two watersheds used as TMDL reference watersheds for the Blacks Run and Cooks Creek sediment TMDLs, and watersheds corresponding to several other biological reference sites in the same region. Because sediment was identified as the pollutant responsible for the benthic impairment, the comparison of watershed characteristics focused, not only on geologic and ecologic similarities, but also on sediment-generating characteristics. Minimal differences exist among the eco-region classifications for all of the potential reference watersheds. All watersheds are in the Central Appalachian Ridges and Valleys Level III ecoregion, and lie predominantly in the Northern Limestone/Dolomite Valleys Level IV ecoregion. Table 7.1compares the various physical and sediment-related characteristics of the candidate reference watersheds to the characteristics of the impaired watershed. The characteristics chosen to be representative of sediment generation and transport were land use distribution, non-forested average soil erodibility, and average non-forested percent slope. The Universal Soil Loss Equation (USLE) K-factor was used as an index of the erosivity of the soils in the watersheds, and was calculated as a weighted average of the soil K-factors in the watershed.

Table 7.1. Comparison of Physical and Sediment-Related Characteristics

									Non-Forested			2000	
									K-factor	%	meters	Population	
STATIONID	STREAMNAME	ORDER	EcoReg	SubEco	Area_ha	%Urb	%For	%Agr	SSURGO	Slope	Elevation	Non-Sewered	Total
MSS003.01	Mossy Creek *	1	67	67a	4,078	2%	21%	77%	0.32	8.96	444	682	815
Potomac-Shenandoah River													
OPE034.53	Opequon Creek*	2	67	67a	15,123	14%	28%	58%	0.31	5.60	224.1	16,322	19,809
QAL005.18	Quail Run	1	69	69a	349	13%	81%	7%	0.26	10.00	452.9	8	180
STC004.27	Strait Creek	2	67	67a	672	0%	71%	29%	0.24**	18.50	988.3	57	57
STY004.24	Stony Creek	3	67	67a	19,768	1%	87%	12%	0.26	11.67	507.7	2,126	3,112
James River													
BLP000.79	Bullpasture River	3	67	67a	28,495	0%	81%	18%	0.25**	7.73	794.6	527	527
CWP050.66	Cowpasture River	4	67	67a	56,604	0%	86%	14%	0.26**	13.81	748.4	994	994
HYS001.41	Hays Creek	3	67	67a	20,801	0%	52%	48%	0.31	12.53	526.2	1,600	1,600
JKS067.00	Jackson River	3	67	67a	31,429	0%	81%	19%	0.26**	13.93	848.7	705	705
New River													
TOM002.19	Toms Creek	1	67		9,070	2%	72%	26%	0.31	12.92	662.7		9,482
SNK012.06	Sinking Creek	3	69		12,860	0%	62%	38%	0.30**	18.24	771.6	928	928

* Landuse data from DOQQ   - Impaired Watershed   **STATSGO soils
- Closest Matches

7.2.2. The Selected Reference Watershed

Based on the information presented in the previous two sections, the Upper Opequon Creek watershed was selected as the reference watershed for Mossy Creek. Land use distribution was considered a highly important characteristic for this comparison, and the Upper Opequon was the only potential reference watershed with reasonably similar land uses to Mossy Creek. The Upper Opequon watershed is located in the same Level III ecoregion as Mossy Creek and shares the same major Level IV ecoregion. The other characteristics - K-factors, slope, elevation, and percent non-sewered populations - were very comparable to those of Mossy Creek.

7.3. Sediment TMDL Modeling Endpoint

The reference watershed approach for Mossy Creek uses the sediment loading rate in the area-adjusted, non-impaired Upper Opequon watershed as the TMDL target endpoint. Reductions from various sources will be specified in the alternative TMDL scenarios that achieve the TMDL target within the impaired Mossy Creek watershed. Reductions in sediment load to levels found in the reference watershed are expected to allow benthic conditions to return to a non-impaired state.

CHAPTER 8: MODELING PROCESS FOR TMDL DEVELOPMENT

8.1. Source Assessment of Sediment

Sediment is generated in the Mossy Creek watershed through the processes of surface runoff, streambank and channel erosion, as well as from background geologic forces. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, and urban land uses.

8.1.1. Surface Runoff

During runoff events, sediment loading occurs from both pervious and impervious surfaces around the watershed. For pervious areas, soil is detached by rainfall impact or shear stresses created by overland flow and transported by overland flow to nearby streams. This process is influenced by vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices. During periods without rainfall, dirt, dust and fine sediment build up on impervious areas through dry deposition, which is then subject to washoff during rainfall events. Sediment generated from impervious areas can be reduced through the use of management practices that reduce the surface load subject to washoff.

8.1.2. Channel and Streambank Erosion

Pasture areas accessible to streams are often associated with sediment loading through the activity of livestock on their streambanks. Livestock hooves on streambanks detach clumps of soil, and push the loosened soil downslope and into streams adjacent to these areas, delivering sediment to the stream independent of runoff events. Impervious areas tend to increase the percentage of rainfall that runs off the land surface leading to larger volumes of runoff with higher peak flows and greater channel erosion potential.

8.1.3. Point Source TSS Loads

Fine sediment is included in total suspended solids (TSS) loads that are contributed from the one single family home included under the 1,000-gpd general permit within the watershed.

8.1.4. Spring Flow Inputs

As mentioned previously (Section 3.1.1), there are four major springs that discharge into Mossy Creek. Total suspended solids loads from these springs were monitored on several occasions as described in Table 8.1. Contributions of TSS from the springs were only detected in two of seven samples in Mount Solon spring and one of five samples in Kyle's Mill spring (Table 8.1). These three samples where TSS were present showed very low levels of TSS in the spring water. Therefore, when modeling sediment, the spring flows were not assigned a TSS load.

Table 8.1. Total Suspended Solids Concentrations in Mossy Creek Springs.

Date	Mount Solon Spring	Blue Hole Spring	Kyle's Mill	Cress Pond
	TSS in mg/L			
8/16/2002	ND	ND	--	--
9/18/2002	ND	ND	ND	--
10/2/2002	4	--	--	ND
11/21/2002	3	ND	1	ND
3/12/2003	ND	ND	ND	--
4/30/2003	ND	ND	ND	--
5/20/2003	ND	ND	ND	--

ND = Not Detected

8.2. GWLF Model Description

The Generalized Watershed Loading Functions (GWLF) model was developed for use in ungaged watersheds (Haith et al., 1992), and was chosen for the modeling required for the Mossy Creek TMDL. The loading functions, upon which the model is based, are compromises between the empiricism of export coefficients and the complexity of chemical simulation models. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff and sediment, dissolved and attached nitrogen and phosphorus loads delivered to streams from complex watersheds with a combination of point and non-point sources of pollution. The model considers flow inputs from both surface runoff and groundwater. The hydrology in the model is simulated with a daily water balance procedure that takes into consideration types of storages within the system. Runoff is generated based on the Soil Conservation Service's Curve Number method as presented in Technical Release 55 (SCS, 1986). Erosion is generated using a modification of the Universal Soil Loss Equation. Sediment supply uses a delivery ratio together with the erosion estimates, and sediment transport takes into consideration the transport capacity of the runoff. Stream bank and channel erosion was calculated using an algorithm by Evans (2002) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model.

The GWLF model operates on three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains primarily input data related to hydrology and sediment transport, while the nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types. The Visual Basic™ version of GWLF with modifications for use with ArcView was used in this study (Evans et al., 2001). The following additional modifications related to sediment were made to the Penn State Visual Basic version of the GWLF model, as incorporated in their ArcView interface for the model, AvGWLF v. 3.2:

- Urban sediment buildup was added as a variable input.
- Urban sediment washoff from impervious areas was added to total sediment load.
- Formulas for calculating monthly sediment yield by land use were corrected.
- Mean channel depth was added as a variable to the streambank erosion calculation.

8.3. Supplemental Post-Model Processing

After modeling was performed on individual and cumulative sub-watersheds, and total watersheds, the model output was post-processed in a Microsoft Excel™ spreadsheet to summarize the modeling results and to account for existing levels of agricultural best management practices (BMPs) already implemented within the Mossy Creek watershed.

The effect of existing agricultural BMPs was based on the Virginia Department of Conservation and Recreation's State Cost-Share Database and through an assessment of fenced exclusion of livestock from streams. The DCR database tracks the implementation of BMPs within each state HUP watershed. These data are then used by EPA's Chesapeake Bay Program to calculate sediment reduction and pass-through fractions of the sediment load from each land use in each HUP for use with the Chesapeake Bay model and with the Virginia 2002 Statewide NPS Pollution Assessment (Yagow et al., 2002). Since Mossy Creek lies within the B19 watershed, the sediment pass-through fractions for each land use category within B19 were related to, and applied to, the modeled land use categories used for this TMDL study. Modeled sediment loads within each land use category were then multiplied by their respective pass-through fractions to simulate the reduced loads resulting from existing BMPs.

8.4. Input Data Requirements

8.4.1. Climate Data

For calibration purposes, the climate in Mossy Creek watershed was characterized by meteorological observations from five rainfall monitoring stations operated by the Biological Systems Engineering. Three of the stations (PMA, PMB, PMC) are located in Mossy Creek and two in the neighboring Long Glade Run watershed (PLB, PLC). A daily precipitation time series was created from Thiessen-weighted precipitation from these five stations. Since the period of record at these stations unfortunately corresponded to extremely dry conditions, a longer period of weather was chosen for modeling TMDL loads that was more reflective of a wider range of precipitation conditions, as shown in Table 8.2. From earlier work with the statewide NPS assessment as part of Virginia's 2002 305(b) report (Yagow, 2002), two separate statewide Thiessen polygon layers had been created, one from 152 available National Weather Service (NWS) daily weather stations in Virginia for precipitation data from 1984 through 1994, and another from 140 stations for data from 1995 through June 2000. The longer period of weather chosen for TMDL modeling for Mossy Creek consisted of the daily sequence of precipitation and temperature values that were calculated as Thiessen-weighted averages of values from the three closest stations for the 1984-1994 period and from the two closest stations for 1995-2000. Precipitation and temperature values were converted to their respective metric units (cm and °C) for use with the GWLF model. Missing data and distributions in the weather file were filled in based on the available weather records from surrounding stations. Weather data for calibrating the TMDL reference watershed - Upper Opequon Creek – was obtained from the Winchester 7 SE station (449186), with daily rainfall values substituted from the Winchester WINC station (449181) on days where a better correspondence was indicated between rainfall and stream response. The stations and periods of record used for the various watersheds and modeling procedures are summarized in Table 8.3. The location of Mossy Creek and the various precipitation stations are shown in Figure 8.1.

Table 8.2. Comparison of Annual Precipitation for Calibration and TMDL Modeling

Precipitation Summary	No. of Years			
	Dry (< 80 cm)	Normal (80-110 cm)	Wet (> 110 cm)	Average (cm)
Mossy Creek (BSE)	4			69.6
TMDL Modeling	3	9	3	96.9

Table 8.3. Weather Data Sources.

Type of Modeling	Weather Data Station	NWS ID	Period	No. of Years
Mossy Creek Calibration	PMA, PMB, PMC, PLB, PLC		Jan 1999 - Dec 2002	4
Upper Opequon Creek Calibration	Winchester 7 SE	449186	Jan 1988 - Sep 1997	9.75
	Winchester WINC	449181		
TMDL Modeling	Dale Enterprise	442208	Jan 1985 - Dec 1999	15
	Staunton	448062		
	West Augusta	448975		

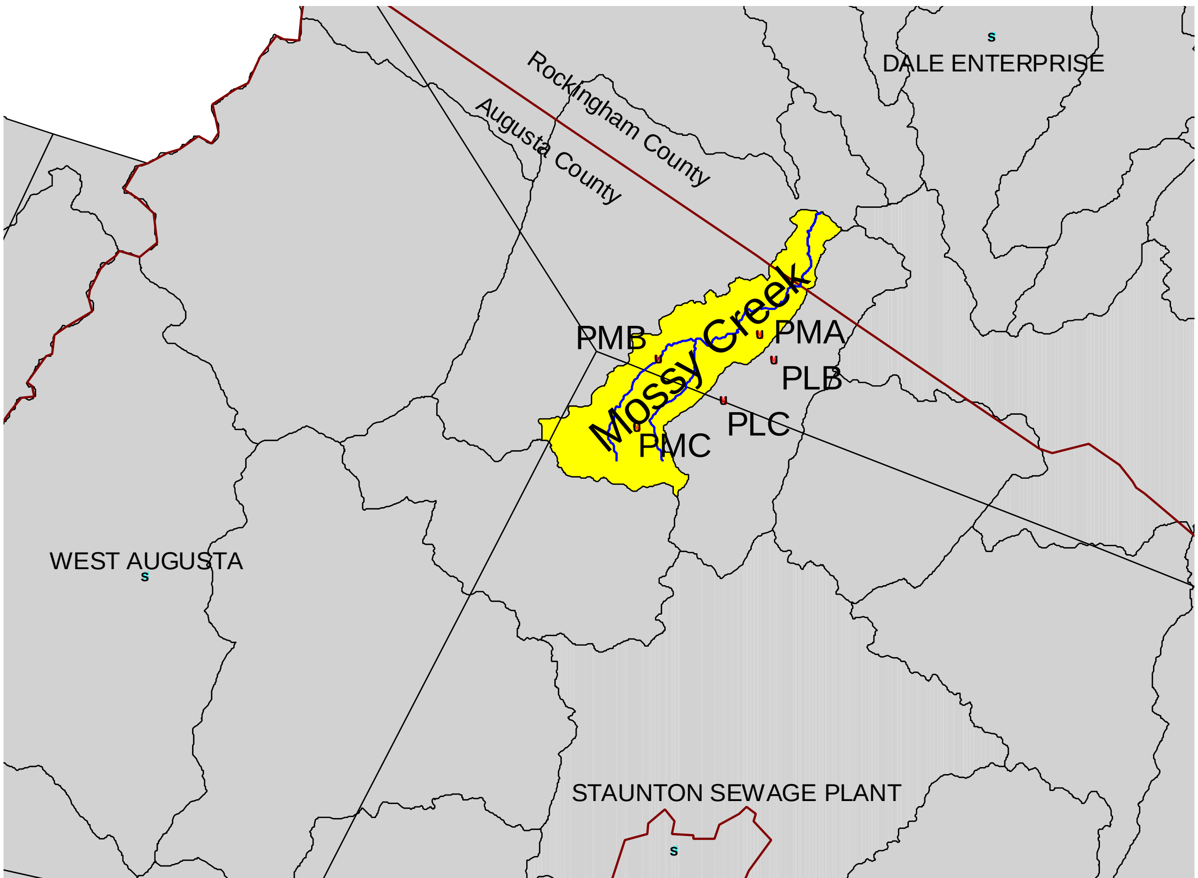

Figure 8.1. Location of Mossy Creek and Weather Stations

8.4.2. Land Use

Using 1997 aerial photographs, Virginia DCR (VADCR) identified 26 land use types and created a digital land use layer for the Mossy Creek watershed. In May and September of 2002, Virginia Tech personnel verified these land uses. A similar digital land use layer for the Upper Opequon Creek watershed had been digitized previously by VADCR for another project. The VADCR land use classification categories were consolidated into a smaller number of categories based on the similarities in associated sediment sources, as shown in Table 8.4. The cropland category, however, was subdivided into “Hi-Till” and “Lo-Till” based on percentages assessed during the 2002 Statewide NPS Pollution Assessment study (Yagow et al., 2002). The resulting 13 land use categories and their distribution within the Mossy Creek and Upper Opequon Creek watersheds are shown in Table 8.5. During modeling with GWLF, the pervious and impervious portions of the residential and commercial categories were modeled separately, leading to 17 categories of land use. Land use within Mossy Creek was assumed not to change significantly in the near future, so TMDL allocation scenarios were modeled based on existing land use conditions.

Table 8.4. Consolidation of VADCR Land Use Categories for Mossy Creek

TMDL Land Use Categories	Pervious/Impervious (percentage)	VADCR Land Use Categories
Cropland	Pervious (100%)	Cropland (211)
Pasture 1	Pervious (100%)	Improved pasture (2121)
Pasture 2	Pervious (100%)	Unimproved pasture (2122)
Pasture 3	Pervious (100%)	Overgrazed pasture (2123)
Urban Grass	Pervious (100%)	Open urban (18)
Orchards	Pervious (100%)	Orchards (22)
Forest	Pervious (100%)	Forest (4)
Transitional	Pervious (100%)	Barren (7), Urban transition (16) Harvested forest (44), Confined cattle (231)
Low Density Residential (LDR)	Pervious (88%) Impervious (12%)	LDR (111) Wooded residential (118)
Medium Density Residential (MDR)	Pervious (70%) Impervious (30%)	MDR (112), Farmstead (241) Mobile homes (115)
High Density Residential (HDR)	Pervious (35%) Impervious (65%)	HDR (113)
Commercial	Pervious (21%) Impervious (79%)	Commercial (12), Industrial (13) Transportation/Utilities (14) Animal waste facility (242)

Table 8.5. Land Use Distribution in Mossy Creek and Upper Opequon Creek Watersheds

Land Use Category	Opequon Creek (ha)	Area-adjusted Opequon Creek (ha)	Mossy Creek (ha)
Hi-Till cropland	454.0	124.6	162.0
Lo-Till cropland	347.9	95.5	398.7
Pasture, improved	6,150.3	1,688.2	2,322.0
Pasture, unimproved	946.9	259.9	186.9
Pasture, poor	30.6	8.4	0.0
Urban Grass	350.1	96.1	0.0
Orchard	604.9	166.0	0.0
Forest	4,188.4	1,149.7	854.0
Transitional	70.0	19.2	1.8
LDR-pervious	277.5	76.2	104.3
MDR-pervious	520.3	142.8	16.5
HDR-pervious	18.2	5.0	0.0
Com-pervious	121.4	33.3	0.8
LDR-impervious	37.8	10.4	14.2
MDR-impervious	223.0	61.2	7.1
HDR-impervious	33.8	9.3	0.0
Com-impervious	456.8	125.4	2.9
Total Land Area	**14,832.0**	**4,071.2**	**4,071.2**
% Agriculture	57.5%	57.5%	75.4%
% Forest	28.2%	28.2%	21.0%
% Urban	13.7%	13.7%	3.6%

8.4.3. Hydrologic Parameters

All parameters were evaluated in a consistent manner between the two watersheds, in order to ensure their comparability for the reference watershed approach. Except for those parameters calibrated to observed flow (described in a later section), all other GWLF parameter values were evaluated from a combination of GWLF user manual guidance, AVGWLF procedures, procedures developed during the 2002 statewide NPS pollution assessment (Yagow et al., 2002), and best professional judgment. Parameters were generally evaluated using GWLF manual guidance, except where noted otherwise. Hydrologic and sediment parameters are all included in GWLF's transport input file, with the exception of urban sediment buildup rates, which are in the nutrient input file. Descriptions of each of the hydrologic parameters are listed below according to whether the parameters were related to the overall watershed, to the month of the year, or to individual land uses.

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity, and further refined during calibration.
- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph.
- Seepage coefficient (day-1): The seepage coefficient represents the amount of flow lost as seepage to deep storage.

The following parameters were initialized by running the model for a 9-month period prior to the chosen period during which loads were calculated:

- Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.
- Initial saturated storage (cm): Initial depth of water stored in the saturated zone.
- Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.
- Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the first day in the weather file

Month-Related Parameter Descriptions

- Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that all annual detached sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar-year basis.
- ET_CV: Composite evapotranspiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.
- Hours per Day: Mean number of daylight hours.
- Erosion Coefficient: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.

Land Use-Related Parameter Descriptions

- Curve Number: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event, evaluated using SCS TR-55 guidance.

8.4.4. Sediment Parameters

Watershed-Related Parameter Descriptions

- Sediment delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans et al., 2001).

Land Use-Related Parameter Descriptions

- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.
- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997).
- Daily sediment buildup rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Streambank Erosion Parameter Descriptions (Evans, 2002)

- % Developed land: percentage of the watershed with urban-related land uses – defined as all land in MDR, HDR, and COM land uses, as well as the impervious portions of LDR.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- Stream length: calculated as the total stream length of natural stream channel, in meters. Excludes any non-erosive hardened and piped sections of the stream.
- Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling, in meters.
- Mean channel depth (m): calculated from relationships developed for the Chesapeake Bay Watershed Model by physiographic region, of the general form – $y = a * A^b$, where y = mean channel depth in ft, and A = drainage area in square miles.

8.5. Accounting for Sediment Pollutant Sources

8.5.1. Surface Runoff

Pervious area sediment loads were modeled explicitly in the GWLF model using sediment detachment, a modified USLE erosion algorithm, and a sediment delivery ratio to calculate edge-of-watershed loads, reported on a monthly basis by land use. Impervious area sediment loads were modeled explicitly in the GWLF model using an exponential buildup-washoff algorithm.

8.5.2. Channel and Streambank Erosion

Streambank erosion was modeled explicitly within the GWLF model using a modification of the routine included in the AVGWLF version of the GWLF model (Evans et al., 2001). This routine calculates average annual streambank erosion as a function of: percentage developed land, average area-weighted curve number (CN) and K-factors, watershed animal density, streamflow volume, bank height, and total stream length in the watershed.

8.5.3. Point Source

There are no permitted point sources in Mossy Creek except for one single family home permitted under the 1000-gpd general permit in the watershed. The load from the single family home unit was calculated as the maximum permitted daily flow and maximum TSS concentration allowed under this type of permit (1000 gpd and 30 mg/L). This translated into an annual TSS load of 0.041 t/yr as shown in Table 8.6.

Table 8.6. Permitted TSS Loads in Mossy Creek Watershed

SFH General Permits	Permitted Daily Flow (MGD)	Permitted Ave. TSS Conc. (mg/L)	Permitted Annual TSS Load (t/yr)
VAG401083	0.001	30	0.041

8.6. Accounting for Critical Conditions and Seasonal Variations

8.6.1. Critical Conditions

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area, and included “dry”, “normal” and “wet” years, as shown previously in Table 8.2. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – and critical conditions during high flow – generally associated with nonpoint source loads.

8.6.2. Seasonal Variability

The GWLF model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model also allows for monthly-variable parameter inputs for evapotranspiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

8.7. GWLF Calibration for Hydrology

The GWLF model was originally developed for use in ungaged watersheds (Haith et al., 1992). However, the BasinSim adaptation of the model (Dai et al., 2000) recommends hydrologic calibration of the model, and preliminary calibrated model results in a previous study for the gaged Linville Creek watershed showed an 18% reduction in the percent error between simulated and observed monthly runoff. Since concurrent flow and precipitation observed data were available at both Mossy Creek and its reference watershed - the Upper Opequon Creek, hydrologic calibration was performed on both watersheds. Both watersheds were calibrated in a similar manner, consistent with the assumptions in the reference watershed approach, in order to establish a target sediment load from the TMDL reference watershed.

The purpose of calibration was to adjust parameter values within the model so that simulated model output more closely matched observed data. By calibrating to total flow and seasonal flow distribution, simulation of the hydrology-dependent sediment load components should also be more representative of watershed conditions.

Daily flow rates for Mossy Creek were available from the Biological Systems Engineering monitoring station QMA located in Rockingham County, just upstream from where state road 747 crosses the creek. Monitoring at this station began in May 1998 and ended in December 2002. The Upper Opequon Creek watershed had been monitored at USGS station 01615000, just upstream from its confluence with Abrams Creek, and had daily stream flow data available from October 1943 through October 17, 1997. Concurrent sets of daily observed precipitation and flow data were obtained for each station's calibration period, as specified in Table 8.3, and compared with GWLF simulated flow for each watershed.

GWLF uses daily rainfall inputs and generates monthly runoff outputs. Hydrologic calibration was performed based on monthly runoff (flow) totals. The parameters adjusted during hydrologic calibration included the recession coefficient, the seepage coefficient, the soil available water content (AWC), and area-weighted dormant- and growing season-ET cover coefficients.

Spreadsheets were constructed and used to analyze model output after each model run, and to calculate parameter adjustments for the next iteration of calibration. Within the spreadsheets, comparisons were made between simulated and observed runoff for the flow components, seasonal distribution, monthly runoff time series, and cumulative runoff. Base flow was calibrated through adjustments to the recession and seepage coefficients, while seasonal distribution was calibrated by adjusting the area-weighted dormant- and growing season-ET cover coefficients. The AWC parameter was adjusted to improve baseflow response during summer of 1998 under extremely dry weather conditions.

The results of the hydrologic calibration for Mossy Creek are presented as a monthly runoff time series in Figure 8.2, cumulative runoff in Figure 8.3, and flow and seasonal distributions in Table 8.7. Corresponding results for Upper Opequon Creek are presented in Figure 8.4, Figure 8.5, and Table 8.8.

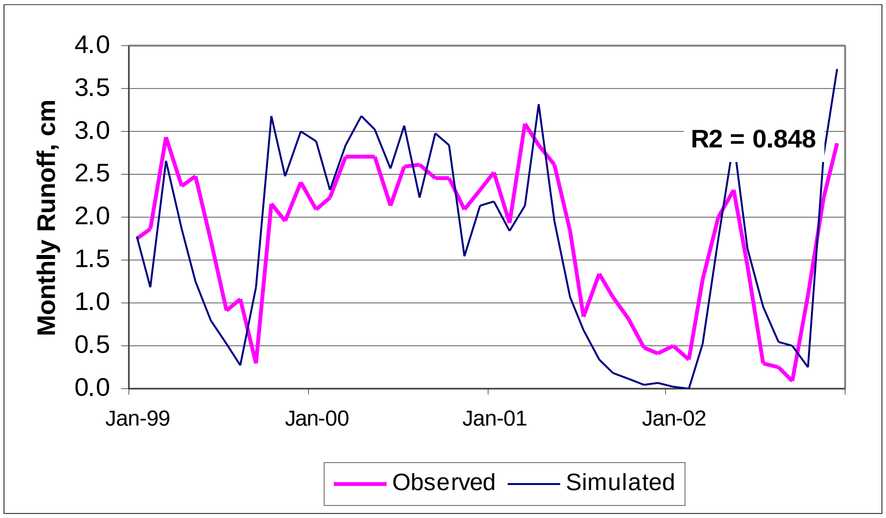

Figure 8.2. Calibration Monthly Runoff Time Series – Mossy Creek

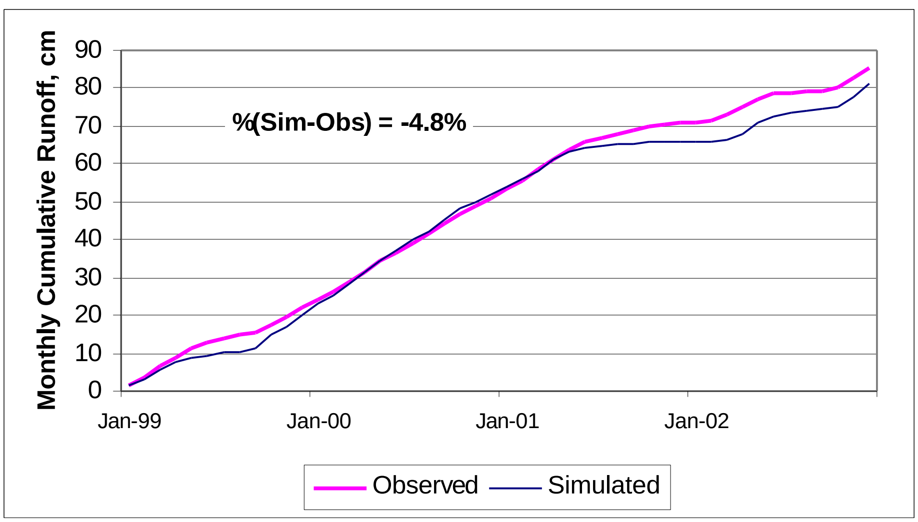

Figure 8.3. Calibration Cumulative Runoff – Mossy Creek

Table 8.7. Calibration Flow Distributions – Mossy Creek – 1998-2002

Flow Distribution Components	SIMULATED (cm/yr)	SIMULATED (% of Total)	OBSERVED (cm/yr)	OBSERVED (% of Total)	Sim-Obs (cm/yr)	Sim-Obs (% of Total)
Total Runoff	20.32		21.35		-1.03	-4.8%
Total Surface Runoff	1.05	5.1%	0.50	2.3%	0.55	
Total Baseflow	19.28	94.9%	20.86	97.7%	-1.58	
Winter (Dec-Feb) Runoff	4.36	22.5%	4.59	22.2%	-0.23	-4.9%
Spring (Mar-May) Runoff	6.85	35.3%	7.50	36.4%	-0.65	-8.7%
Summer (Jun-Aug) Runoff	3.67	18.9%	4.26	20.6%	-0.59	-13.8%
Fall (Sep-Nov) Runoff	4.51	23.3%	4.29	20.8%	0.22	5.2%

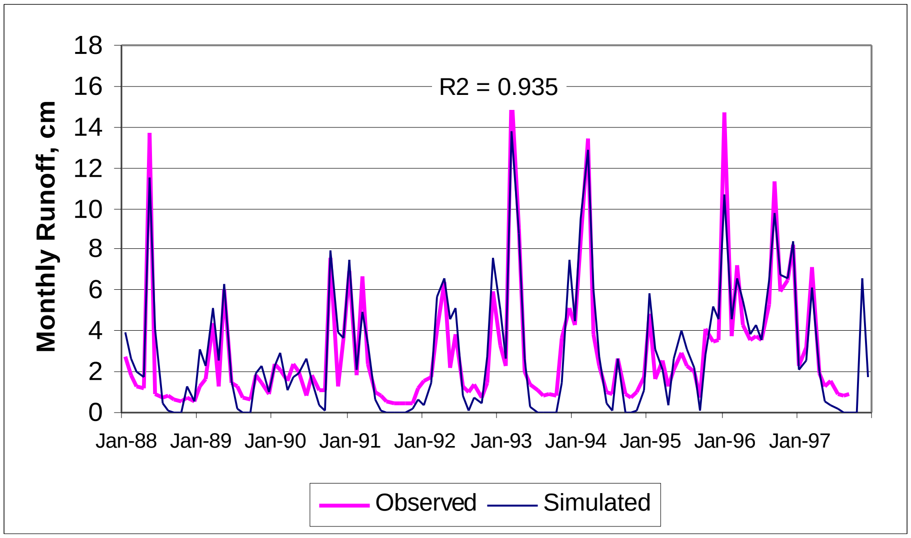

Figure 8.4. Calibration Monthly Runoff Time Series – Upper Opequon Creek

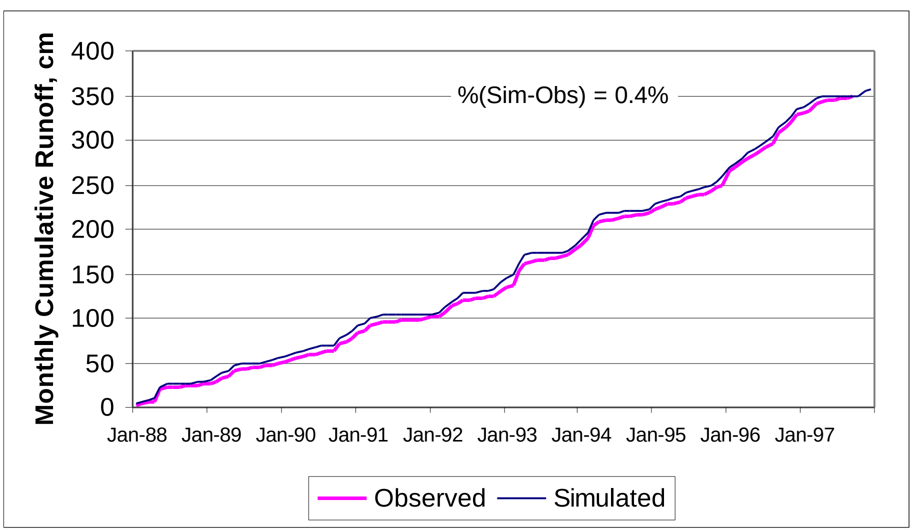

Figure 8.5. Calibration Cumulative Runoff – Upper Opequon Creek

Table 8.8. Calibration Flow Distributions – Upper Opequon Creek – 1988-1997

Flow Distribution Components	SIMULATED		OBSERVED		Sim-Obs	
	(cm/yr)	(% of Total)	(cm/yr)	(% of Total)	(cm/yr)	(% of Total)
Total Runoff	35.83		35.64		0.18	0.5%
Total Surface Runoff	4.92	13.7%	19.06	53.5%	-14.14	
Total Baseflow	30.90	86.3%	16.58	46.5%	14.33	
Winter (Dec-Feb) Runoff	11.81	33.0%	10.69	30.0%	1.11	10.4%
Spring (Mar-May) Runoff	13.61	38.0%	13.43	37.7%	0.19	1.4%
Summer (Jun-Aug) Runoff	4.48	12.5%	4.87	13.7%	-0.39	-8.0%
Fall (Sep-Nov) Runoff	5.92	16.5%	6.65	18.7%	-0.73	-10.9%

The monthly runoff time series for Mossy Creek showed a generally good correspondence between observed and simulated monthly runoff, with a correlation coefficient of 0.848. Total simulated runoff was 4.8% less than the observed value. The simulated percentages of runoff distributed among seasons were all within 10% of observed values, except for summer (-13.8%). The difference between observed and simulated individual season average annual runoff totals were within ±0.65 cm/yr.

The monthly runoff time series for Upper Opequon Creek also showed a generally good correspondence between observed and simulated monthly runoff, with a correlation coefficient of 0.935. Total simulated runoff was only 0.4% less than the observed value. The seasonal percentages of runoff were all within 11% of observed values. The difference between observed and simulated individual season average annual runoff totals were within ±1.1 cm/yr.

In summary, the correlations between simulated and observed total runoff in both watersheds were quite good with correlation coefficients above 84.8%. Cumulative monthly runoff over the 15-year period was matched within 4.8% of observed totals. A slightly larger variability was seen in the distribution among seasons, although even these were all within 10%, except for the summer season in the Mossy Creek watershed. Since the reference watershed approach uses average loading over long periods and utilizes comparably parameterized and calibrated watersheds, the calibrated GWLF model should provide reasonable load comparisons for TMDL development.

The GWLF parameter values evaluated and/or calibrated for both watersheds are shown in Table 8.9 through Table 8.11. Table 8.9 lists the various watershed-wide parameters and their values, Table 8.10 displays the monthly variable evapotranspiration cover coefficients, and Table 8.11 shows the land use-related parameters – runoff curve numbers (CN) and the Universal Soil Loss Equation's KLSCP product for erosion modeling.

Table 8.9. GWLF Watershed Parameters

GWLF Watershed Parameters	units	Mossy Creek	Upper Opequon Creek	Upper Opequon Creek Area-adjusted
recession coefficient	(day^{-1})	**0.019**	**0.060**	**0.060**
seepage coefficient	(day^{-1})	**0.000**	**0.010**	**0.010**
sediment delivery ratio		0.1492	0.1016	0.1492
unsaturated water capacity	(cm)	**9.80**	13.93	13.93
erosivity coefficient (Nov - Apr)		0.1	0.1	0.1
erosivity coefficient (growing season)		0.3	0.3	0.3
% developed land	(%)	3.6	13.7	13.7
no. of livestock	(AU)	4871	1090	297
area-weighted soil erodibility		0.321	0.297	0.297
area-weighted runoff curve number		73.11	74.46	74.46
total stream length	(m)	25,266.7	114,488.7	31,246.3
stream length with livestock access	(m)	9,183.0	33,393.9	9,113.9
calculated aFactor		0.0000512	0.0000763	0.0000763
mean channel depth	(m)	0.963	1.380	0.963

Table 8.10. GWLF Monthly Evapotranspiration Cover Coefficients

Watershed	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Mossy Creek	0.669	0.677	0.680	**0.680**	0.680	0.671	0.608	0.545	0.518	**0.500**	0.590	0.651
Upper Opequon Creek	0.844	0.849	0.850	**0.850**	0.850	0.845	0.810	0.775	0.760	**0.750**	0.800	0.834
Upper Opequon Creek Area-adjusted	0.844	0.849	0.850	**0.850**	0.850	0.845	0.810	0.775	0.760	**0.750**	0.800	0.834

* July values represent the maximum composite ET coefficients during the growing season.
** Jan values represent the minimum composite ET coefficients during the dormant season.

Table 8.11. GWLF Land Use Parameters – Existing Conditions

	Mossy Creek		Upper Opequon Creek		Upper Opequon Creek Area-adjusted	
Land Use	KLSCP	CN	KLSCP	CN	KLSCP	CN
Hi-Till cropland	0.3915	84.8	0.1206	85.1	0.1206	85.1
Lo-Till cropland	0.1724	82.9	0.0531	83.3	0.0531	83.3
Pasture, improved	0.0039	71.1	0.0014	71.6	0.0014	71.6
Pasture, unimproved	0.0209	76.8	0.0051	77.0	0.0051	77.0
Pasture, poor	0.0000	84.4	0.0197	84.7	0.0197	84.7
Urban Grass	0.0000	76.1	0.0060	76.4	0.0060	76.4
Orchard	0.0000	73.6	0.0005	73.8	0.0005	73.8
Forest	0.0009	70.1	0.0005	70.5	0.0005	70.5
Transitional	0.0625	89.9	0.1631	90.1	0.1631	90.1
LDR-pervious	0.0039	74.3	0.0016	74.8	0.0016	74.8
MDR-pervious	0.0034	79.1	0.0012	79.4	0.0012	79.4
HDR-pervious	0.0000	88.9	0.0009	89.1	0.0009	89.1
Com-pervious	0.0033	91.6	0.0010	91.6	0.0010	91.6
LDR-impervious	0.0000	88.1	0.0000	88.2	0.0000	88.2
MDR-impervious	0.0000	98.0	0.0000	98.0	0.0000	98.0
HDR-impervious	0.0000	98.0	0.0000	98.0	0.0000	98.0
Com-impervious	0.0000	98.0	0.0000	98.0	0.0000	98.0

In order to further ascertain the appropriateness of the calibrated model for Mossy Creek, a variety of average annual metrics were calculated from simulated Mossy Creek outputs using the wider range of precipitation inputs to the model as used for TMDL modeling and shown in Table 8.12. These are compared with observed or modeled outputs from other watersheds or monitoring gages in the region. Precipitation input is a weighted average of the two NWS stations shown, and is comparable to that used in two previous TMDLs. Evapotranspiration is slightly lower, but close to that in Abrams Creek. Surface runoff - amount and % of total precipitation - are comparable to Toms Brook. The area-normalized flow is within the range of two USGS stations in the region. Baseflow as a % of total streamflow is at the high end of the range of values shown, which is consistent with a watershed dominated by flow from springs. The unit area sediment load is higher than the two watersheds shown, but not unreasonable for a watershed with a higher % agriculture than the two watersheds shown. The channel erosion as a % of total load is within, and at the lower end of, the range shown. All in all, the Mossy Creek hydrologic and sediment average values modeled over the wide range of precipitation inputs appear to be reasonable for this region.

Table 8.12. Mossy Creek Simulated Metrics Compared with Regional Watersheds

		USGS Flow Stations		NWS Weather Stations		Previous TMDLs	
Annual Average Values	**Mossy Creek**	**North River 01620500**	**Abrams Creek 01616000**	**Dale Enterprise 442208**	**Staunton STP 448062**	**Abrams Creek**	**Toms Brook**
Watershed Area (sq.mi.)	14.7	17.2	16.5			19.1	16.4
Averaging Period	1985-1999	1985-1998	1980-1993	1985-2001	1985-1999	1982-1987	1985-1994
Precipitation (cm)	96.91			91.04	100.8	93.20	93.56
Evapotranspiration (cm)	45.08					47.95	62.70
Surface Runoff (cm)	5.65					16.97	5.76
Surface Runoff (% of Precipitation)	5.8%					18.2%	6.2%
Area-normalized Flow (cfsm)	1.32	1.49	1.28			0.97	0.90
Baseflow (% of Total Streamflow)	89.1%	45.7%	77.3%			61.9%	81.4%
Sediment Load (t/ha)	5.01					0.71	1.17
Channel Erosion (% of Total Load)	6.0%					61.6%	5.0%

CHAPTER 9: TMDL ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

9.1. Bacteria TMDL

9.1.1. Background

The objective of the bacteria TMDL for Mossy Creek and Long Glade Run was to determine what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDL were 126 cfu/100mL (calendar-month geometric mean) and 235 cfu/100mL (single sample maximum). The TMDL considers all sources contributing fecal coliform and *E. coli* to Mossy Creek and Long Glade Run. The sources can be separated into nonpoint and point (or direct) sources. The incorporation of the different sources into the TMDL are defined in the following equation:

$$TMDL = WLA + LA + MOS \qquad [9.1]$$

where,

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

While developing allocation scenarios to implement the bacteria TMDL, an implicit margin of safety (MOS) was used by using conservative estimations of all factors that would affect the bacteria loadings in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the worst stream conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

When developing a bacteria TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface; these reductions are presented in the tables in Sections 9.1.2b and 9.1.3b. In the model, this has the effect of reducing the amount of bacteria that reaches the stream, the ultimate goal of the TMDL. Thus, the reductions called for in Sections 9.1.2 and 9.1.3 indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown in Sections 9.1.2 and 9.1.3 are not intended to infer that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (cattle direct deposit, cropland, etc.) will be accomplished by implementing BMPs like filter strips, stream fencing, and off-stream watering; and that required reductions for from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, and other appropriate measures included in the TMDL Implementation Plan.

For both Mossy Creek and Long Glade Run, a three year source allocation period was used. The weather for the period was taken from three non-consecutive years of observed data from the nearby Dale Enterprise weather station. This period was selected because it incorporates average rainfall, low rainfall, and high rainfall years; and the climate during this period caused a wide range of hydrologic events including both low and high flow conditions. The data from the PLC weather station were not used due to the drought conditions under which they were collected.

The calendar-month geometric mean values used in this report are geometric means of the simulated daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, we took the arithmetic mean of the hourly values on a daily basis, and then calculated the geometric mean from these average daily values.

The guidance for developing an *E. coli* TMDL offered by VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, VADEQ suggests the use of a translator equation they developed to convert the daily average fecal coliform concentrations output by the model to daily average *E. coli* concentrations. The translator equation is:

$$E.\ coli \text{ concentration} = 2^{-0.0172} \times (\text{FC concentration}^{0.91905}) \qquad [9.2]$$

where the bacteria concentrations (FC and *E. coli*) are in cfu/100mL.

This equation was used to convert the fecal coliform concentrations output by HSPF to *E. coli* concentrations. Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

9.1.2. Mossy Creek Bacteria TMDL

9.1.2.a. Existing Conditions

Analysis of the simulation results for the existing conditions in the watershed (Table 9.1) show that contributions from pervious land segments are the primary source of *E. coli* in the stream. Contributions from the upland pervious land segments account for approximately 61% of the concentration at the watershed outlet. Direct deposition of manure by cattle into Mossy Creek is responsible for approximately 34% of the mean daily *E. coli* concentration. The next largest contributors are direct deposits to streams by wildlife (2%), springs

(1%), and straight pipes (1%). Runoff from impervious areas contributed less than 1% of the mean daily *E. coli* concentration.

Table 9.1. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Mossy Creek watershed.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100mL	Relative Contribution by Source
All Sources	714	
Nonpoint source loadings from pervious land segments	437	61%
Direct deposits of cattle manure to stream	244	34%
Direct nonpoint source loadings to the stream from wildlife	17	2%
Direct nonpoint source loadings from springs	10	1%
Straight-pipe discharges to stream	4	1%
Nonpoint source loadings from impervious land use	<1	<1%

The contribution of each of the sources detailed in Table 9.1 to the calendar-month geometric *E. coli* concentration is shown in Figure 9.1. Although there are dates in Figure 9.1, as mentioned previously the weather data used are from non-consecutive years and the dates in the figure are only those given to HSPF for modeling purposes; they do not represent actual dates and cannot be compared to other information from that period. As indicated in this figure, the calendar-month geometric mean value is dominated by contributions from direct deposits of cattle to streams, and these deposits alone result in violations of the calendar-month geometric mean goal of 126 cfu/100mL. Because contributions from upland areas drop during non-runoff conditions between storm events, the contributions from the upland pervious areas to the calendar month geometric mean *E. coli* concentration are much less than their contributions to the daily average concentration. For the same reason, ILS contributions to the calendar month geometric mean concentrations are too small to be represented in Figure

9.1. In-stream *E. coli* concentrations from direct nonpoint sources, particularly cattle in streams, are highest during the summer when stream flows are lowest. This is expected because cattle tend to spend more time in streams during the summer months; because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load. Contributions from wildlife direct deposit and from upland pervious areas (PLS) to the calendar month geometric mean concentration are roughly equivalent as shown in Figure 9.1. Contributions from bacteria loads from springs fall below the wildlife direct deposit contributions, and straight pipe contributions are significantly lower than the other sources in the graph.

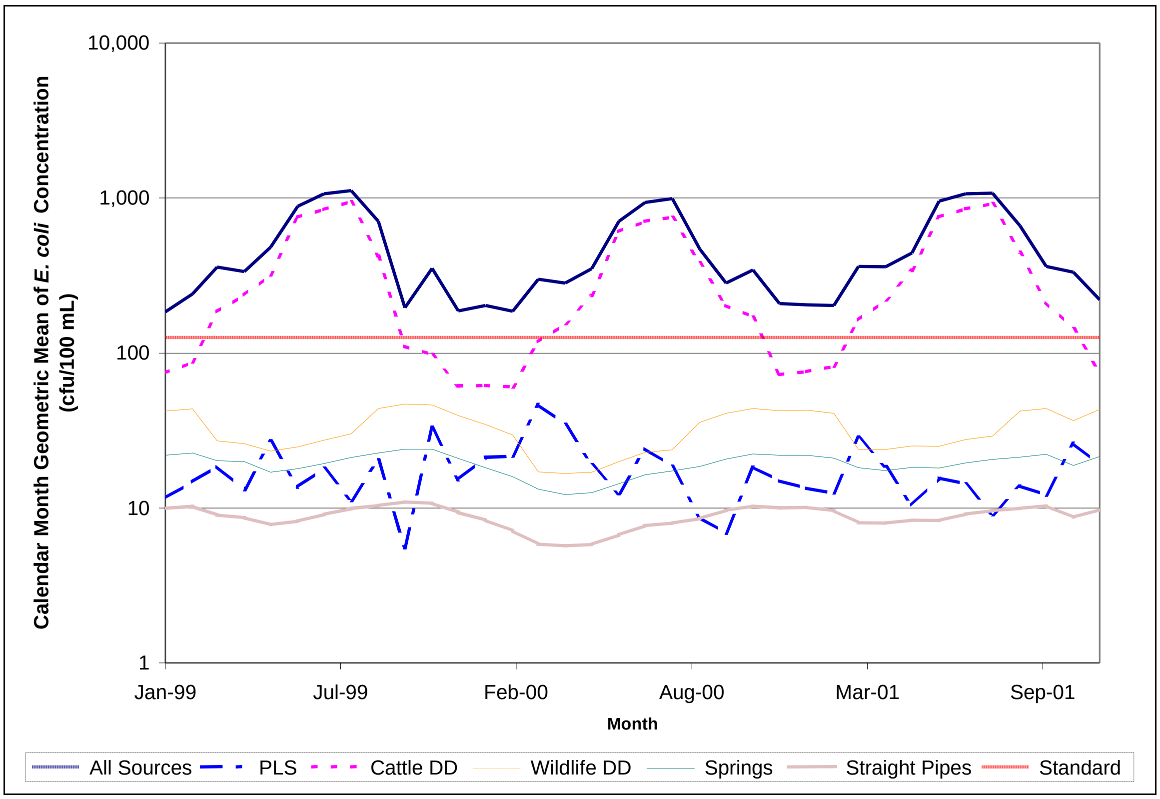

Figure 9.1. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Mossy Creek watershed.

9.1.2.b. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the single sample limit of 235 cfu/100mL. The scenarios and results are summarized in Table 9.2; recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. Because direct deposition of *E. coli* by cattle into streams was responsible for 34% of the mean daily *E. coli* concentration (Table 9.1) and the vast majority of the calendar-month geometric mean concentration, all scenarios considered required reductions in, or elimination of, direct deposits by cattle.

In all scenarios considered in Table 9.2, non-permitted straight-pipe contributions from on-site waste disposal systems were eliminated because these contributions are illegal under existing state law. Nonpoint source contributions from impervious land segments were neglected because their contribution to the calendar-month geometric mean and the daily average concentrations is negligible (Table 9.1). In scenario 01, straight-pipes were eliminated and large reductions (at least 50%) were taken from land surface loads (cropland, pasture, loafing lots, and residential). This had little effect, decreasing the violations of the geometric mean standard and the instantaneous standard by 3% and 7%, respectively (Table 9.2). Scenarios 02 through 04 took increasing reductions from all sources while still not meeting the standard. The progression from Scenario 02 to the successful scenarios (scenarios 05 and 06) shows that high reductions are required from PLS areas. Scenario 03 illustrates that a high reduction in cattle direct-deposit will be required. Scenario 04 illustrates that increasing the wildlife direct-deposit reduction to an extreme level (99%) will not produce a viable source reduction scenario without additional reductions from the other sources. Scenarios 05 and 06 both meet both *E. coli* standards. It should be noted that the cattle and wildlife direct-deposit source reductions are less in Scenario 06 than in Scenarios 05, but the cropland reduction is greater. Scenario 06 was selected as the TMDL allocation because it calls for lower reductions for wildlife direct-deposit than Scenario 05. The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 9.2 for the TMDL allocation (Scenario 06), along with the standards.

Table 9.2. Bacteria allocation scenarios for the Mossy Creek watershed.

Scenario Number	% Violation of *E. coli* standard		Required Fecal Coliform Loading Reductions to Meet the *E coli* Standards,%						
	Geomean	Single Sample	Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	Straight Pipes	All Residential PLS
Existing Conditions	100%	48%	0	0	0	0	0	0	0
1	97%	41%	0	50	50	100	0	100	50
2	0.0%	0.1%	94	95	97	100	0	100	95
3	0.0%	0.1%	94	95	95	100	30	100	95
4	0.0%	0.1%	99	95	95	100	99	100	95
5	0.0%	0.0%	99	90	98	100	30	100	95
6	0.0%	0.0%	94	95	98	100	0	100	95

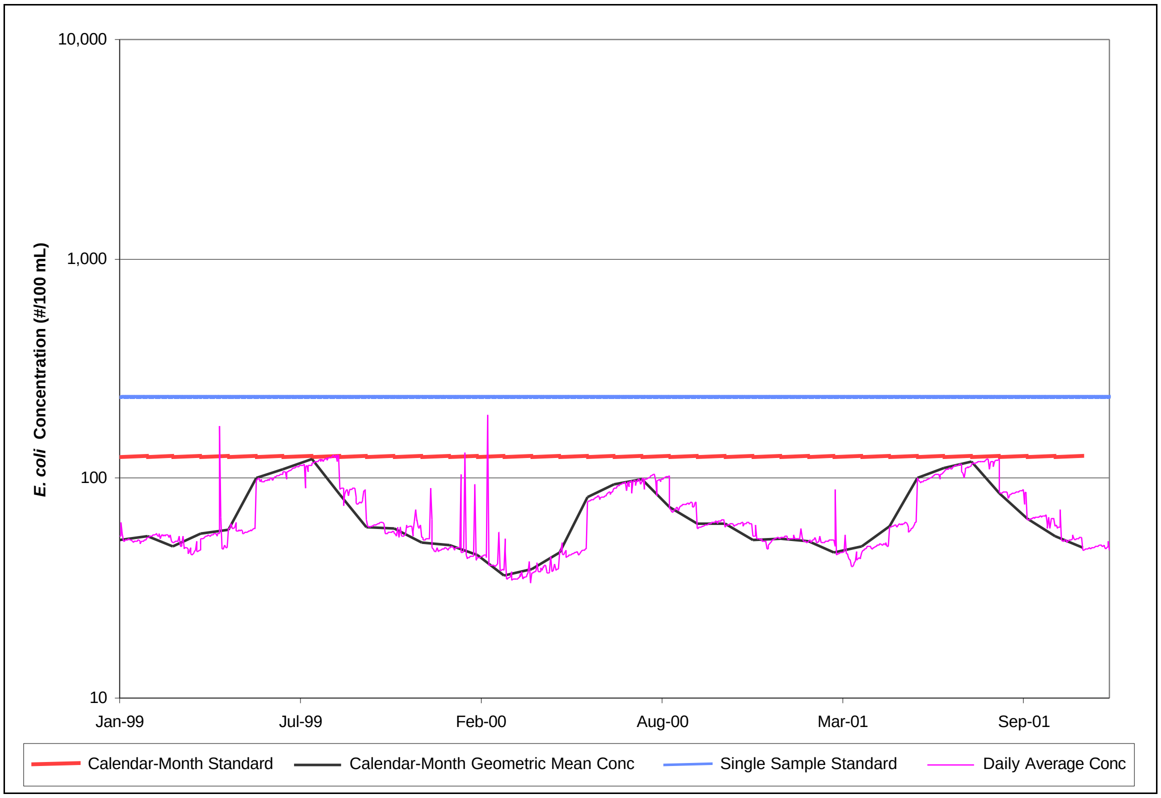

Figure 9.2. Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation (Allocation Scenario 06 from Table 9.2) for Mossy Creek.

Loadings for existing conditions and the TMDL allocation scenario (Scenario 06) are presented for nonpoint sources by land use in Table 9.3 and for direct nonpoint sources in Table 9.4. It is clear that extreme reductions in both loadings from land surfaces and from sources directly depositing in the streams of Mossy Creek are required to meet both the calendar-month geometric mean and single sample standards for *E. coli*. Cattle deposition directly in streams dominates the *E. coli* contributions to the stream, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimum dilution due to reduced stream flow. Loadings from upland areas are reduced during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas becomes a major contributor to the in-stream concentration.

Because these upland loadings are intermittent, they are not a primary source of violations of the calendar-month geometric mean standard, but do cause many violations of the *E. coli* single sample standard.

Table 9.3. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 06).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load (× 10^{12} cfu)	Percent reduction from existing load
Cropland	666	1%	33.3	95%
Pasture	51,500	97%	1,030	98%
Residential[a]	238	<1%	11.9	95%
Loafing Lot	852	2%	0	100%
Forest	103	<1%	103	0%
Total	53,600	100%	1,170	98%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 9.4. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 06).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load (× 10^{12} cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load (× 10^{12} cfu)	Percent reduction
Cattle in streams	189	89%	11.3	94%
Straight Pipes	3.40	2%	0	100%
Wildlife in Streams	12.5	6%	12.5	0%
Spring Contributions	6.7	3%	6.7	0%
Total	212	100%	30.5	86%

The fecal coliform loads presented in Table 9.3 and Table 9.4 are the fecal coliform loads that result in in-stream *E coli* concentrations that meet the applicable *E coli* water quality standards after application of the VADEQ fecal coliform to *E coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

The influence of the bacteria concentration from the springs on the water quality in Mossy Creek was investigated. It was discovered that the reduction required from cattle direct deposits to streams could be decreased to 92% if the bacteria input from the springs could be attenuated through the implementation of appropriate BMPs.

9.1.2.c. Waste Load Allocation

Waste load allocations were assigned to the one point source facility located in the Mossy Creek watershed (Table 9.5). The point source was represented in the allocation scenarios by its current permit conditions; no reductions were required from the point source in the TMDL. Current permit requirements are expected to result in attainment of the *E. coli* WLA as required by the TMDL. Point source contributions, even in terms of maximum flow, are minimal. Therefore, no reasonable potential exists for these facilities to have a negative impact on water quality and there is no reason to modify the existing permits. The point source facilities are discharging at their criteria and therefore cannot cause a violation of the water quality criteria.

Table 9.5. Point Sources Discharging Bacteria in the Mossy Creek Watershed.

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated *E. coli* Load (WLA) (cfu/year)
VAG401083	General Permit Facility	0.001	200 cfu/ 100 mL	$2.76*10^9$	$2.76*10^9$	$1.74*10^9$

9.1.2.d. Summary of Mossy Creek's TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed for Mossy Creek. The TMDL addresses the following issues:

1. The TMDL meets the calendar-month geometric mean and single sample water quality standards.

2. Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations for which the bacteria TMDL was developed.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Mossy Creek watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean criterion; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions. Violations of the instantaneous criterion were associated primarily with storm flows.

6. Both the flow regime and bacteria loading to Mossy Creek are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 94% reduction in direct deposits of cattle manure to streams, elimination of all unpermitted straight-pipe discharges, a 95% reduction in nonpoint source loadings to cropland and residential areas, and a 98% reduction in nonpoint source loadings to pasture land. Using Eq. [9.1], the summary of the bacteria TMDL for Mossy Creek for the selected allocation scenario (Scenario 06) is given in Table 9.6. In Table 9.6, the WLA was obtained by multiplying the permitted point source's fecal coliform discharge concentration by its allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 9.6. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Mossy Creek bacteria TMDL.

Parameter	SWLA	SLA	MOS	TMDL
E. coli	1.74×10^9 *(VAG401083=1.74×10^9)*	$15{,}919 \times 10^9$	NA	$15{,}921 \times 10^9$

NA – Not Applicable because MOS was implicit

9.1.3. Long Glade Run Bacteria TMDL

9.1.3.a. Existing Conditions

Analysis of the simulation results for the existing conditions in the watershed (Table 9.7) show that cattle direct deposits of manure to streams is the primary source of *E. coli* in the stream, accounting for 60% of the mean daily *E. coli* in the stream. Nonpoint source loadings from pervious land segments (manure applied to cropland, pastures, and forests by livestock, wildlife, and other NPS sources) are the next largest contributors of *E. coli* in the stream, accounting for 37% of daily *E. coli* concentrations. Next comes wildlife with 3% of the mean daily in-stream *E. coli* concentration. Nonpoint source loadings from impervious areas are responsible for less than 1% of the mean daily *E. coli* concentration.

Table 9.7. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for the existing conditions in the Long Glade Creek watershed.

Source	Mean Daily *E. coli* Concentration by Source,	Relative Contribution by Source

	cfu/100mL	
All sources	656	
Direct deposits of cattle manure to stream	394	60%
Nonpoint source loadings from pervious land segments	243	37%
Direct nonpoint source loadings to the stream from wildlife	20	3%
Nonpoint source loadings from impervious land use	<1	<1%

As shown in Table 9.7, direct *E. coli* loadings by cattle in the stream result in higher mean daily *E. coli* concentrations (394 cfu/100 mL) than do *E. coli* loadings from pervious upland areas (243 cfu/100 mL). The contribution of each of these sources to the calendar-month geometric *E. coli* concentration is shown in Figure 9.3. As indicated in this figure, the calendar-month geometric mean value is dominated by contributions from direct deposits of cattle to streams, and these deposits alone result in many violations of the calendar-month geometric mean goal of 126 cfu/100mL. In-stream *E. coli* concentrations from direct nonpoint sources, particularly cattle in streams, are highest during the summer when stream flows are lowest. This is expected because cattle spend more time in streams during the summer months; because of the low flow conditions, there is less stream flow for dilution of the direct deposit manure load. The same is true for the direct deposit from wildlife, to a lesser extent. The violations due to direct deposits from wildlife at the beginning of the allocation period suggest that some reductions in wildlife loadings will be required in the final TMDL allocation. Figure 9.3 shows roughly equivalent contributions to the calendar month geometric mean *E. coli* concentration from wildlife direct deposit and from nonpoint source loadings from pervious land segments (PLS). The contributions from pervious land segments to the calendar month geometric mean concentration are less than to the daily average concentration because of the decrease in PLS contributions during non-runoff conditions between storm events that lowers calculated calendar month geometric mean concentration.

Finally, the calendar-month geometric means for impervious land segments were so low they were not included in Figure 9.3.

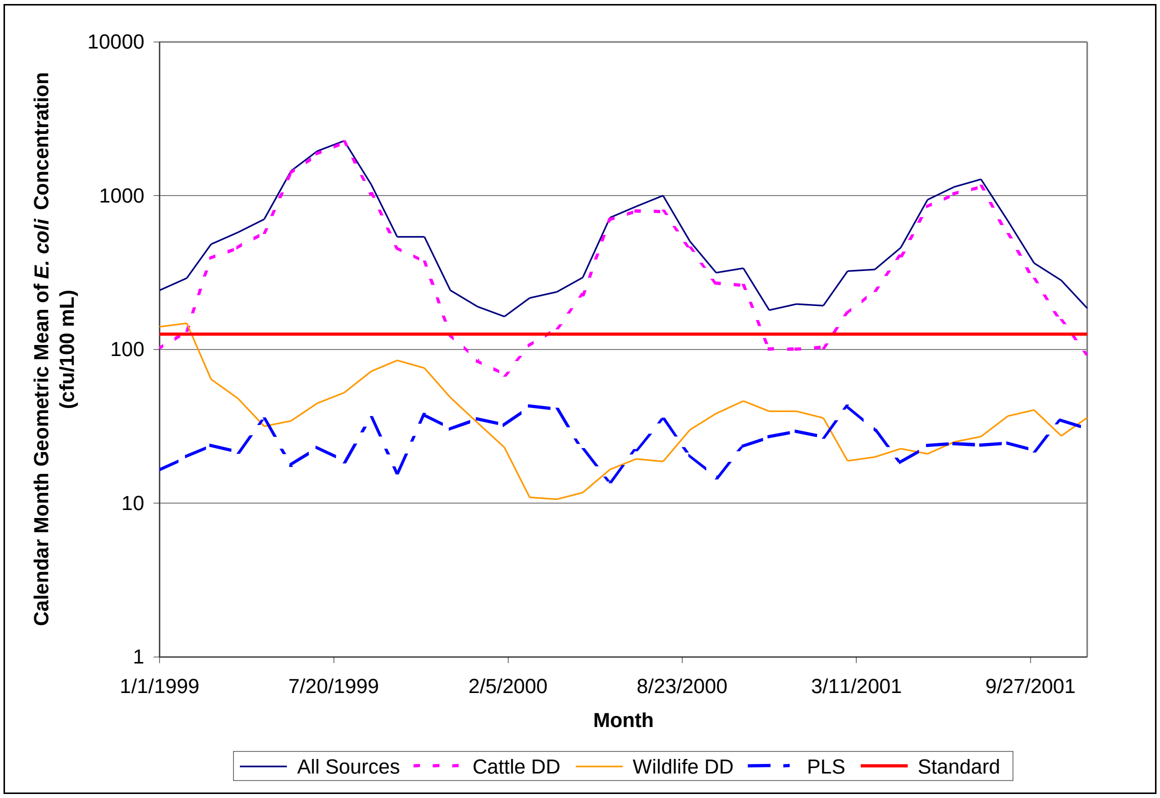

Figure 9.3. Relative contributions of different *E. coli* sources to the calendar-month geometric mean *E. coli* concentration for existing conditions in the Long Glade Run watershed.

<u>9.1.3.b. Allocation Scenarios</u>

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean of 126 cfu/100mL and the single sample limit of 235 cfu/100mL. The scenarios and results are summarized in Table 9.8; recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. Because direct deposition of *E. coli* by cattle into streams was responsible for 60% of the mean daily *E. coli* concentration (Table 9.6), and almost all of the calendar-month geometric mean concentration, all scenarios considered required large reductions of direct deposits by cattle to the stream.

In all the proposed scenarios, reductions in wildlife direct-deposit to streams were minimized to ensure a practically implementable scenario. An initial attempt at moderate reductions (50% for all source categories but wildlife, Scenario 01) yielded only a 6% reduction in the geometric mean violation rate and a 12% reduction in the instantaneous violation rate, indicating that larger source reductions would likely be necessary to meet the water quality standard. For this watershed, it is impossible to meet the water quality standard without wildlife direct-deposit reductions. Large reductions (≥ 95%) in cropland and pasture are also required to meet the standard. The fact that large (≥ 98%) cattle direct-deposit source reductions are needed is evident beginning with Scenario 02. The three successful source reduction scenarios (07 – 09) all indicated the need for reductions from the residential PLSs. These successful scenarios also illustrate the tradeoff between the cattle and wildlife direct-deposit source categories. While Scenarios 07 through 09 all meet both the geometric mean and the single sample standards for *E. coli*, Scenario 09 was selected as reductions in wildlife direct-deposit are minimized without calling for the complete elimination of livestock direct-deposit. All successful scenarios called for large reductions in the loafing lot loadings to streams.

The concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 9.4 for the TMDL allocation (Scenario 09), along with the standards.

Table 9.8. Bacteria allocation scenarios for Long Glade Run watershed.

	% Violation of *E. coli* Standard		Fecal Coliform Loading Reduction Required to Meet the *E coli* Standards, %					
Scenario Number	**Geomean**	**Single Sample**	**Cattle DD**	**Cropland**	**Pasture**	**Loafing Lot**	**Wildlife DD**	**All Residential PLSs**
Existing Conditions	100%	57%	0	0	0	0	0	0
1	94%	45%	50	50	50	50	0	50
2	6%	0%	100	100	100	100	0	100
3	0%	0.07%	99	90	90	99	50	99
4	3%	0%	97	95	95	100	35	95

5	3%	0%	99	95	95	100	25	85
6	0%	0.07%	99	95	95	100	30	25
7	0%	0%	98	95	95	100	35	30
8	0%	0%	100	95	95	100	25	30
9	0%	0%	99	95	95	100	30	30

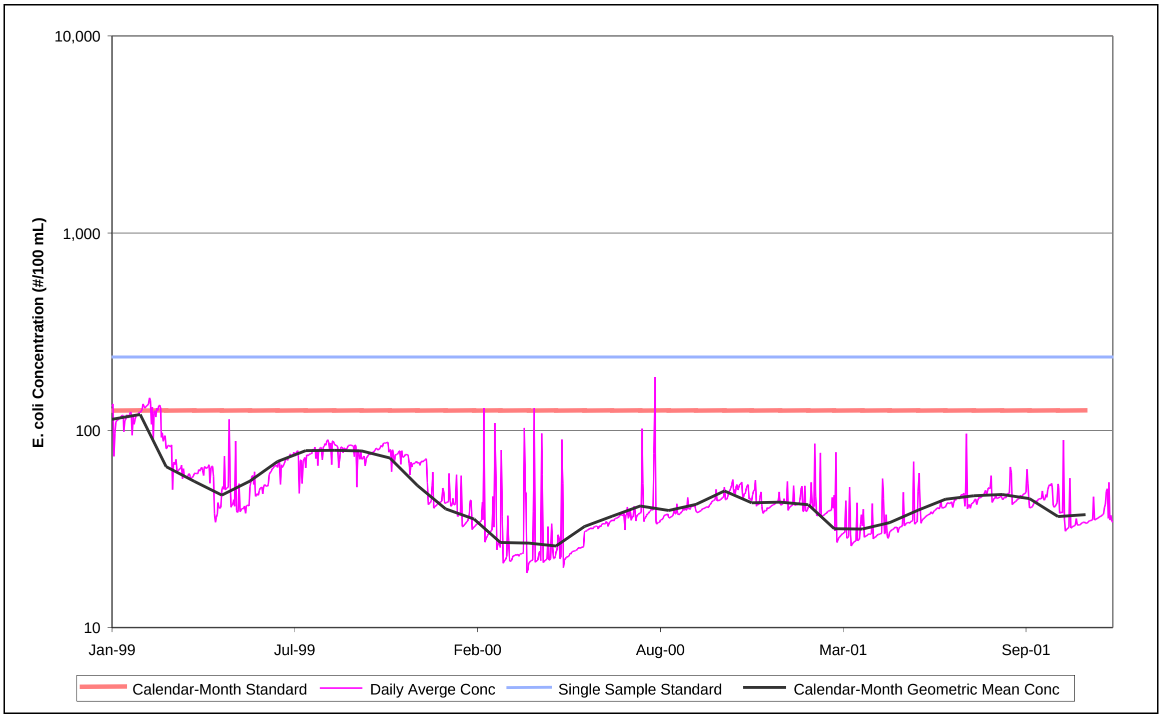

Figure 9.4. **Calendar-month geometric mean standard, single sample standard, and successful *E. coli* TMDL allocation (Allocation Scenario 09 from Table 9.8)**

Loadings for existing conditions and for the successful TMDL allocation scenario (Scenario 09) are presented for nonpoint sources by land use in Table 9.9 and for direct nonpoint sources in Table 9.10. It is clear that extreme reductions in both loadings from land surfaces and from sources directly depositing in the streams of Long Glade Run are required to meet both the calendar-month geometric mean and single sample standards for *E. coli*. Cattle deposition directly in streams dominates the *E. coli* contributions to the stream, particularly during the summer months when cattle spend more time in the stream, flows are lower, and there is minimum dilution due to reduced stream flow. Loadings from upland areas are reduced during these periods because there is little upland runoff to transport fecal coliform to streams. When high flow conditions do occur, however, the large magnitude of the nonpoint source loadings coming from upland areas will result in violations of the water quality standard. Because these upland loadings are intermittent, they are not a primary source of violations of the calendar-month geometric mean standard, but do cause many violations of the *E. coli* single sample standard.

Table 9.9. Annual nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 09).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	572	1%	28.6	95%
Pasture	48,700	96%	2,440	95%
Residential[a]	206	<1%	144	30%
Loafing Lot	1140	2%	0	100%
Forest	92.3	<1%	92.3	0%
Total	50,700	100%	2,700	95%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 9.10. Annual direct nonpoint source fecal coliform loads under existing conditions and corresponding reductions for TMDL allocation scenario (Scenario 09).

Source	Existing Condition		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total direct deposited load from direct nonpoint sources	TMDL direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction
Cattle in streams	55.7	96%	0.557	99%
Wildlife in Streams	2.53	4%	1.77	30%
Total	58.2	100%	2.33	96%

The fecal coliform loads presented in Table 9.9 and Table 9.10 are the fecal coliform loads that result in in-stream *E coli* concentrations that meet the applicable *E coli* water quality standards after application of the VADEQ fecal coliform to *E coli* translator to the HSPF predicted mean daily fecal coliform concentrations.

9.1.3.c. Waste Load Allocation

Waste load allocations were assigned to each point source facility in the Long Glade Run watershed (Table 9.11). Point sources were represented in the allocation scenarios by their current permit conditions; no reductions were required from point sources in the TMDL. Current permit requirements are expected to result in attainment of the *E. coli* WLA as required by the TMDL. Point source contributions, even in terms of maximum flow, are minimal. Therefore, no reasonable potential exists for these facilities to have a negative impact on water quality and there is no reason to modify the existing permits. The point source facilities are discharging at their criteria and therefore cannot cause a violation of the water quality criteria. Note that the *E. coli* WLA value presented in Table 9.12 represents the sum of all point source *E. coli* WLAs in Long Glade Run.

Table 9.11. Point Sources Discharging Bacteria in the Long Glade Run Watershed.

Permit Number	Facility	Flow (MGD)	Permitted FC Conc.	Permitted FC Load (cfu/year)	Allocated FC Load (cfu/year)	Allocated *E. coli* Load (WLA) (cfu/year)
VAG401481	General Permit Facility	0.001	200 cfu/ 100 mL	$2.76*10^9$	$2.76*10^9$	$1.74*10^9$
VAG401746	General Permit Facility	0.001	200 cfu/ 100 mL	$2.76*10^9$	$2.76*10^9$	$1.74*10^9$
VAG401919	General Permit Facility	0.001	200 cfu/ 100 mL	$2.76*10^9$	$2.76*10^9$	$1.74*10^9$

9.1.3.d. Summary of Long Glade Run's TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed for Long Glade Run. The TMDL addresses the following issues:

1. The TMDL meets the calendar-month geometric mean and single sample water quality standards.

2. Because *E coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E coli* concentrations for which the bacteria TMDL was developed.

3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.

4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Long Glade Run watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean criterion; however, because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions. Violations of the instantaneous criterion were associated primarily with storm flows.

6. Both the flow regime and bacteria loading to Long Glade Run are seasonal. The TMDL accounts for these seasonal effects.

The selected *E. coli* TMDL allocation that meets both the calendar-month geometric mean and single sample water quality goals requires a 99% reduction in direct deposits of cattle manure to streams, elimination of contributions by loafing lots, a 30% reduction in direct deposits by wildlife to streams, a 30% reduction in loadings to all residential pervious surfaces, and a 95% reduction in nonpoint source loadings to the agricultural land surfaces. Using Eq. [9.1], the summary of the bacteria TMDL for Long Glade Run for the selected allocation scenario (Scenario 09) is given in Table 9.12. In Table 9.12, the WLA was obtained by summing the products of each permitted point source's fecal coliform discharge concentration and allowable annual discharge. The LA is then determined as the TMDL – WLA.

Table 9.12. Annual *E. coli* loadings (cfu/year) used for the Long Glade Run bacteria TMDL.

Parameter	SWLA	SLA	MOS	TMDL
E. coli	5.23×10^9 *(SSFH WLA = $5.23*10^9$)*	$2{,}315 \times 10^9$	NA	$2{,}320 \times 10^9$

NA – Not Applicable because MOS was implicit

9.2. Sediment TMDL

9.2.1. Background

The sediment TMDL to address a benthic impairment for the Mossy Creek watershed was developed using a reference watershed approach, with the Upper Opequon Creek selected as the TMDL reference watershed. The GWLF model was calibrated for hydrology separately for each watershed. For TMDL modeling, a common weather input data set was used for the 15-yr period, January 1984 – December 1999.

9.2.2. Existing Conditions

The existing sediment loads were modeled for each watershed and are listed in Table 9.13 by land use category, percent of total watershed load, and sediment load unit area loads for individual land uses.

Table 9.13. Existing Sediment Loads

Surface Runoff Sources	Mossy Creek (t/yr)	Mossy Creek (t/ha-yr)	Mossy Creek (%)	Upper Opequon Creek (t/yr)	Upper Opequon Creek (t/ha-yr)	Upper Opequon Creek (%)
High Till	8,455.0	52.2	41.5%	1,825.2	14.6	32.1%
Low Till	9,166.5	23.0	45.0%	826.7	8.7	14.6%
Pasture	1,358.0	0.5	6.7%	730.1	0.4	12.9%
Urban grasses	0.0	0.0	0.0%	113.3	1.2	2.0%
Orchards	0.0	0.0	0.0%	16.0	0.1	0.3%
Forest	96.4	0.1	0.5%	79.9	0.1	1.4%
Transitional	16.5	9.2	0.1%	289.1	15.0	5.1%
Pervious Urban	65.1	0.5	0.3%	49.1	0.2	0.9%
Impervious Urban	0.0	0.0	0.0%	120.8	0.6	2.1%
Other Sources						
Channel Erosion	1,227.2		6.0%	1,628.2		28.7%
Point Sources	0.04		0.0%	2.5		0.0%
Watershed Totals						
Existing Sediment Load (t/yr)	20,385.0			5,680.8		
Area (ha)	4,071.2			4,071.2		
Unit Area Load (t/ha-yr)	5.007			**1.395**		
Target Sediment TMDL Load				**5,680.8**		**t/yr**

The sediment TMDL for Mossy Creek is the sum of the three required components, given previously in equation 9.1, and quantified in Table 9.14.

Table 9.14 Mossy Creek Sediment TMDL (t/yr)

TMDL	WLA	LA	MOS
5,680.8	0.04 VAG401083 = 0.04	5,112.6	568.1

The TMDL for the impaired Mossy Creek watershed was calculated as the average annual sediment load from the area-adjusted Upper Opequon Creek watershed for existing conditions. The margin of safety (MOS) was explicitly specified as 10% of the calculated TMDL to reflect the relative increase in uncertainty, compared to the MOS of 5% typically used in other TMDLs for the more complex modeling of fecal coliform. The waste load allocation (WLA) was included as the contribution from the one 1000 gpd unit covered under the general permit. The load allocation (LA) – the allowable sediment load from nonpoint sources – was calculated as the TMDL minus the MOS minus the WLA.

Changes in future land use distribution and sediment sources were judged to be minimal, and were modeled as constant. The TMDL was based, therefore, on existing land uses and sediment sources.

9.2.3. Waste Load Allocation

A waste load allocation was assigned to the one unit encompassed under the general permit in the Mossy Creek watershed. Point sources were represented in the allocation scenarios the same as they were for existing conditions. The load from the single family home unit was calculated as the maximum permitted daily flow and maximum TSS concentration allowed under this type of permit (1000 gpd and 30 mg/L), or an annual TSS load of 0.041 t/yr. As a permitted source, no reductions were required from this point source in the TMDL. Although there is only one entity classified as a point source in the Mossy Creek watershed, it is specified both individually and as the WLA in Table 9.14.

9.2.4. Allocation Scenarios

For development of the allocation scenarios, overland non-point sediment sources were grouped into the following four categories: Cropland, Pasture, Urban, and Forestry. Additionally, Channel Erosion and Point Sources were listed as separate categories. Three alternative allocation scenarios were developed, as illustrated in Table 9.15.

Table 9.15 Alternative TMDL Load Allocation Scenarios

	Reference	Existing	TMDL Sediment Load Allocations					
Source	Upper Opequon	Mossy Creek	**TMDL Alternative 1**		**TMDL Alternative 2**		**TMDL Alternative 3**	
Category	(t/yr)	(t/yr)	(% reduction)	(t/yr)	(% reduction)	(t/yr)	(% reduction)	(t/yr)
Cropland	2,667.9	17,621.5	86.7%	2,349.2	75.6%	4,303.2	74.9%	4,419.6
Pasture	730.1	1,358.0	0%	1,358.0	75.6%	331.6	74.9%	340.6
Urban	572.3	81.7	0%	81.7	0.0%	81.7	74.9%	20.5
Forestry	79.9	96.4	0%	96.4	0.0%	96.4	74.9%	24.2
Channel Erosion	1,628.2	1,227.2	0%	1,227.2	75.6%	299.7	74.9%	307.8
Point Sources	2.4	0.04	0%	0.04		0.04		0.04
Total	**5,680.8**	**20,385.0**		**5,112.7**		**5,112.7**		**5,112.7**

These three scenarios are defined as follows:

1. TMDL Alternative 1 takes all of the reductions from the largest source category – Cropland.

2. TMDL Alternative 2 takes equal % reductions from the three largest source categories.

3. TMDL Alternative 3 takes equal % reductions from all source categories.

A concurrent bacteria TMDL requires an increased level of Livestock Exclusion from streams that directly affects the sediment loads from channel erosion in Mossy Creek. This reduction benefit (11.6% of existing Channel Erosion) was calculated as the product of the percentage of total stream length with livestock access (25.1%), the percentage reduction of livestock access corresponding with the bacteria TMDL (92%), and an estimated percentage of the channel erosion due to trampling (50%), where livestock had stream access.

9.2.5. Summary of TMDL Allocation Scenario for Sediment

The sediment TMDL for Mossy Creek is 5,680.8 t/yr and will require an overall reduction of 74.9% from existing loads. From the three alternative scenarios explored, Alternative 3 is recommended as the most equitable approach as it requires equal % reductions from all source categories. Sediment load reductions amounting to 141.7 t/ha-yr, or 11.6% reduction of the existing Channel Erosion load, credited from management of the bacteria TMDL, will provide a head start on the reductions required in the above allocations.

The Mossy Creek sediment TMDL was developed to meet the sediment load of the area-adjusted TMDL reference watershed – Upper Opequon Creek. The TMDL was developed to take into account all sediment sources in the watershed from both point and nonpoint sources. The sediment loads were averaged over a 15-year period to take into account both wet and dry periods in the hydrologic cycle, and the model inputs took into consideration seasonal variations and critical conditions related to sediment loading. An explicit 10% margin of safety was added into the final TMDL load calculation.

CHAPTER 10: TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

10.1. TMDL Implementation Process

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria and benthic impairments on Mossy Creek and Long Glade Run. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

10.2. Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the greatest impact on water quality. For example, in agricultural areas of the watershed, the most promising best management practice to address the bacteria TMDL is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;

4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the following Stage 1 scenarios are targeted at controllable, anthropogenic bacteria sources and can serve as starting points for targeting BMP implementation activities.

10.3. Stage 1 Scenarios

The goal of the stage 1 scenarios is to reduce the bacteria loadings from controllable sources (excluding wildlife) such that violations of the instantaneous criterion (235 cfu/100mL) are less than 10 percent. The stage 1 scenarios were generated with the same model setup as was used for the TMDL allocation scenarios. A margin of safety was not used in determining the stage 1 scenarios. It was estimated for modeling purposes that there are no straight pipes in the Long Glade Run watershed. Should any be found during the implementation process, they should be eliminated as soon as possible since they would be illegally discharging fecal bacteria into Long Glade Run and its tributaries.

10.3.1. Mossy Creek Scenario

The final scenario selected for Stage 1 implementation (Scenario 06, Table 10.1) requires a 85% reduction in direct deposits by cattle to streams, reductions (85%) in loadings from pastures, and elimination of all straight-pipes. No reduction in wildlife deposits to the stream is required. A 75% reduction in loafing lot loads is required. Fecal coliform loadings for the existing conditions and the Stage 1 allocation scenario for nonpoint sources by land use are presented in Table 10.2 and for direct nonpoint sources in Table 10.3. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 06 fecal coliform loads are presented graphically in Figure 10.1.

Table 10.1. Allocation scenarios for Stage 1 TMDL implementation for Mossy Creek.

Scenario Number	Single Sample % Violation	% Reduction Required						
		Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	Straight Pipes	All Residential PLS
1	10	85	75	85	80	0	100	75
2	10	85	50	85	75	0	100	50
3	11	85	0	85	65	0	100	0
4	13	80	80	85	80	0	100	80
5	11	85	0	85	70	0	100	0
6	10	85	0	85	75	0	100	0

Table 10.2. Annual nonpoint source load reductions for Stage 1 TMDL implementation for Mossy Creek watershed (Scenario 06).

Land use Category	Existing Conditions		Stage 1 Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total land deposited load from nonpoint sources	Nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	666	1%	666	0%
Pasture	51,500	97%	7,725	85%
Residential[a]	238	<1%	238	0%
Loafing Lot	852	2%	213	75%
Forest	103	<1%	103	0%
Total	53,600	100%	8,945	17%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 10.3. Required direct nonpoint source load reductions for Stage 1 Implementation (Scenario 06).

Source	Existing Condition		Allocation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	Percent of total direct deposited load from direct nonpoint sources	Direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cattle in streams	189	89%	28.3	85%
Straight-Pipes	3.40	2%	0	100%

Wildlife in Streams	12.5	6%	12.5	0%
Spring Contributions	6.7	3%	6.7	0%
Total	212	100%	47.5	78%

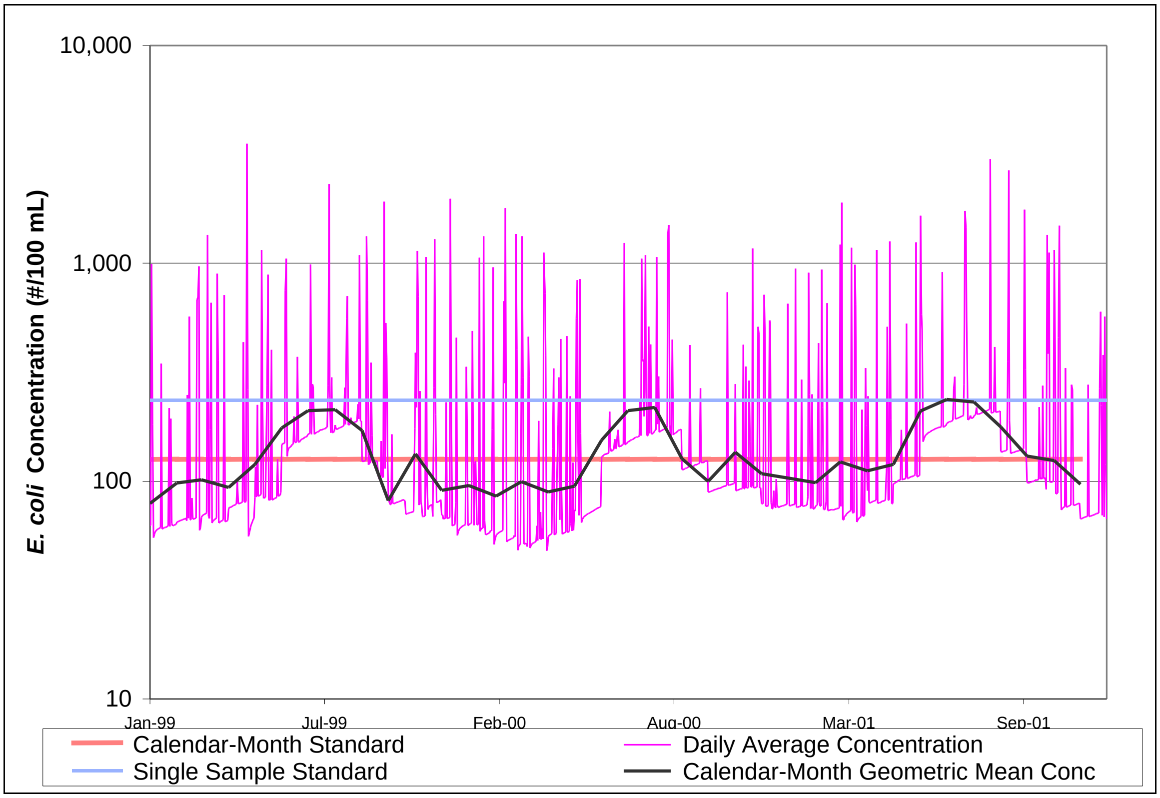

Figure 10.1. Stage 1 TMDL implementation scenario for Mossy Creek.

10.3.2. Long Glade Run Scenario

The final scenario selected for Stage 1 implementation (Scenario 06, Table 10.4) requires a 90% reduction in direct deposits by cattle to streams and reductions (60%) in loadings from cropland and pastures. No reduction in wildlife deposits to the stream is required. A 60% reduction in loafing lot loads is required. Fecal coliform loadings for the existing conditions and for the Stage 1 allocation scenario for nonpoint sources by land use are presented in Table 10.5 and for direct nonpoint sources in Table 10.6. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the Scenario 06 fecal coliform loads are presented graphically in Figure 10.2.

Table 10.4. Allocation scenarios for Stage 1 TMDL implementation for Long Glade Run.

Scenario Number	Single Sample % Violation	% Reduction Required					
		Cattle DD	Cropland	Pasture	Loafing Lot	Wildlife DD	All Residential PLS
1 (existing)	0	99	95	95	100	30	30
2	0	99	90	90	100	0	30
3	13	85	75	75	75	0	30
4	12	90	60	60	60	0	0
5	10	90	75	75	75	0	30
6	10	90	65	65	65	0	0

Table 10.5. Annual nonpoint source load reductions for Stage 1 TMDL implementation for Long Glade Run watershed (Scenario 06).

Land use Category	Existing Conditions		Allocation Scenario	
	Existing conditions load ($\times 10^{12}$ cfu)	Percent of total land deposited load from nonpoint sources	Nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cropland	572	1%	200	65%
Pasture	48,700	96%	17,000	65%
Residential[a]	206	<1%	206	0%
Loafing Lot	1,140	2%	399	65%
Forest	92.3	<1%	92.3	0%
Total	50,700	100%	17,900	65%

[a] Includes loads applied to both High and Low Density Residential and Farmstead

Table 10.6. Required direct nonpoint source fecal coliform load reductions for Stage 1 Implementation Scenario (Scenario 06).

Source	Existing Condition		Allocation Scenario	
	Existing condition load ($\times 10^{12}$ cfu)	Percent of total direct deposited load from direct nonpoint sources	Direct nonpoint source allocation load ($\times 10^{12}$ cfu)	Percent reduction from existing load
Cattle in streams	55.7	96%	5.57	90%
Wildlife in Streams	2.53	4%	2.53	0%
Total	58.2	100%	8.1	14%

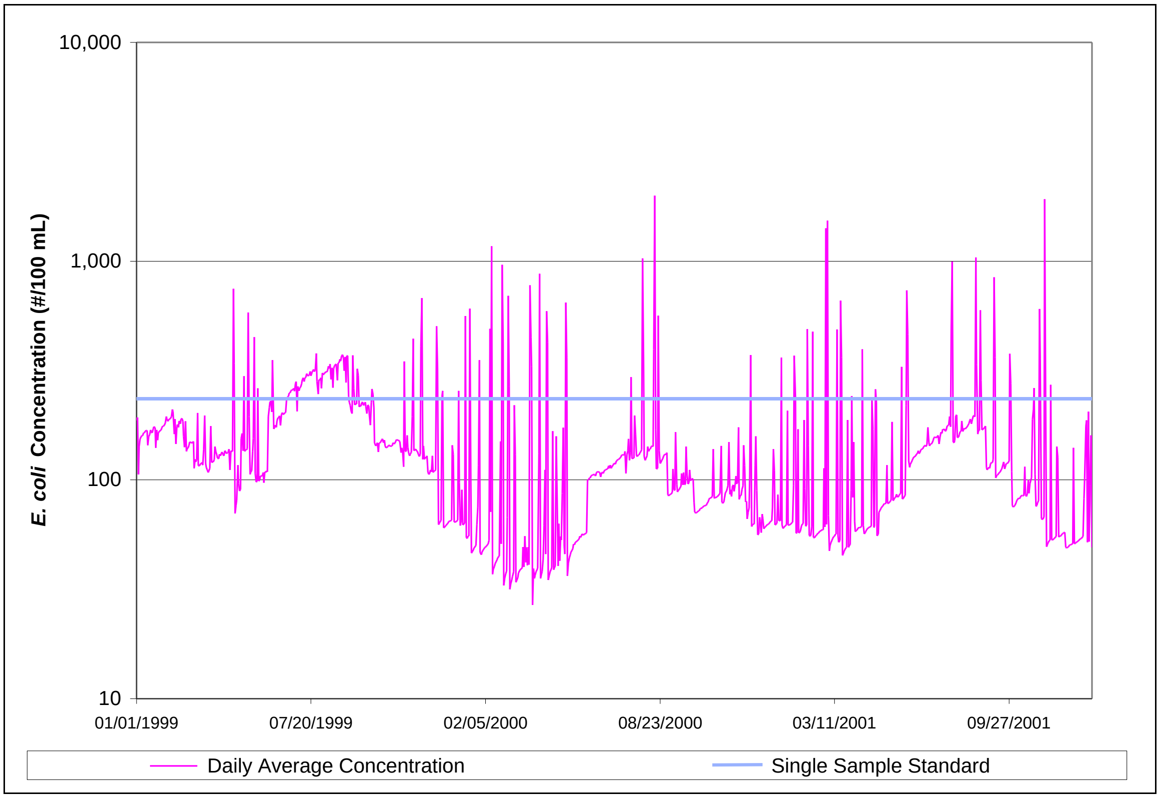

Figure 10.2. Stage 1 TMDL implementation scenario for Long Glade Run.

10.4. Link to ongoing Restoration Efforts

As documented in this report, a portion of the flow from springs that feed Mossy Creek comes from outside of the topographic boundaries of the Mossy Creek watershed. Connections from the North River and Freemason Run to these springs have been documented. Figure 5.5 shows the potential extent of Mossy Creek's hydrologic watershed. The concentrations of bacteria coming from these springs have generally been low; however, these springs are a minor source of bacteria to Mossy Creek that cannot be controlled by implementation efforts within the topographic boundaries of the Mossy Creek watershed. As demonstrated in the TMDL model, the water quality standard can be met with bacteria controls implemented solely within the topographic watershed. Implementation of bacteria controls within the larger hydrologic watershed will speed the implementation process in Mossy Creek and slightly reduce the level of effort specified in the TMDL. TMDL development is underway in the North

River and North River tributaries, including Freemason Run, so implementation of bacteria controls within the larger Mossy Creek hydrologic watershed will be realized.

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. The BMPs required for the implementation of the sediment allocations in the watersheds contribute directly to the sediment reduction goals set as part of the Chesapeake Bay restoration effort. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of the Commonwealth of Virginia Shenandoah and Potomac River Basins Tributary Nutrient Reduction Strategy. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of the strategy described under nonpoint source implementation mechanisms. (VASNR, 1996). A new tributary strategy is currently being developed for the Shenandoah-Potomac River Basin to address the nutrient and sediment reductions required to restore the health of the Chesapeake Bay. Up-to-date information can be found at the tributary strategy web site under http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm.

10.5. Reasonable Assurance for Implementation

10.5.1. Follow-up Monitoring

VADEQ will continue monitoring Mossy Creek (1BMSS001.35, 1BMSS003.01) and Long Glade Run (1BLGC000.96) in accordance with its ambient and biological monitoring programs to evaluate reductions in fecal bacteria counts and improvements in the benthic community, and also the effectiveness of TMDL implementation in attainment of water quality standards.

10.5.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

10.5.3. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

10.5.4. Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. As is the case for Long Glade Run, these streams may not be able to attain standards without some reduction in wildlife load. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria will become effective pending EPA approval and can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 implementation scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 10.2 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

CHAPTER 11: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In May of 2002, members of the Virginia Tech TMDL group traveled to Rockingham County to become acquainted with the watershed. During that trip, they spoke with various stakeholders. In addition, personnel from Virginia Tech, the Headwaters Soil and Water Conservation District (SWCD), and the Natural Resource Conservation Service (NRCS) visited some watershed residents and contacted others via telephone to acquire their input.

The first public meeting was held on June 3, 2003 at the North River Elementary School in Moscow, Virginia to inform the stakeholders of TMDL development process and to obtain feedback on animal numbers in the watershed, fecal production estimates, and to discuss the hydrologic calibration. Copies of the presentation materials and diagrams outlining the development of the TMDL were available for public distribution at the meeting. Approximately 50 people attended the meeting.

The final public meeting was held on March 2, 2004 at the North River Elementary School in Moscow, Virginia to present the draft TMDL report and solicit comments from stakeholders. Approximately 60 people attended the final meeting. Copies of the presentation materials were distributed to the public at the meeting. The public comment period ended on April 2, 2004. A summary of the questions and answers discussed at the meeting was prepared and is located at the VADEQ Valley Regional Office in Harrisonburg, VA.

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APPENDIX A.
Glossary of Terms

Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels

Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data

Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean, lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot} x_n$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

Hydrology

The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Septic system

An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives liquid and solid wastes from a residence or business and a drainfield or subsurface absorption system consisting of a series of tile or percolation lines for disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

APPENDIX B.
Sample Calculation of Cattle
(Sub Watershed MC-8)

Sample Calculation: Distribution of Cattle

(Sub watershed (MC-8) during January)

(Note: Due to rounding, the numbers may not add up.)

Breakdown of the dairy herd is 96 milk cows, 20 dry cows, and 95 heifers.

1. During January, milk cows are confined 75% of the time (Table 4.5). Dry cows and heifers are confined 40% of the time.

Milk cows in confinement	=	96 * (75%)	=	72
Dry cows in confinement	=	20 * (40%)	=	8
Heifers in confinement	=	95 * (40%)	=	38

2. When not confined, dairy cows are on the pasture or in the stream.

Milk cows on pasture and in the stream	=	(96 – 72)	=	24
Dry cows on pasture and in the stream	=	(20 - 8)	=	12
Heifers on pasture and in the stream	=	(95-38)	=	57

3. Twenty-seven percent of the pasture acreage has stream access (Table 4.6) (recall dairy cows are assumed to graze only on Pasture 1). Hence dairy cattle with stream access are calculated as:

Milk cows on pastures with stream access	=	24 * (27%)	=	6.5
Dry cows on pastures with stream access	=	12 * (27%)	=	3.2
Heifers on pastures with stream access	=	57 * (27%)	=	15.4

4. Dairy cattle in and around the stream are calculated using the numbers in Step 3 and the number of hours cattle spend in the stream in January (Table 4.5) as:

Milk cows in and around streams	=	6.5 * (0.5/24)	=	0.14
Dry cows in and around streams	=	3.2 * (0.5/24)	=	0.07
Heifers in and around streams	=	15.4 * (0.5/24)	=	0.32

5. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Section 4.1.2)

Milk cows defecating in streams	=	0.14 * (30%)	=	0.04
Dry cows defecating in streams	=	0.07 * (30%)	=	0.02
Heifers defecating in streams	=	0.32 * (30%)	=	0.10

6. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 5) from number of cattle in pasture and stream (Step 2).

Milk cows defecating on pasture	=	(24 – 0.04)	=	23.96
Dry cows defecating on pasture	=	(12 – 0.02)	=	11.98
Heifers defecating on pasture	=	(57 – 0.10)	=	56.90

APPENDIX C.
Die-off Fecal Coliform During Storage

Die-off of Fecal Coliform During Storage

The following procedure was used to calculate amount of fecal coliform produced in confinement in dairy manure applied to cropland and pasture. All calculations were performed on spreadsheet for each sub watershed with dairy operations in a watershed.

1. It was determined from a producer survey in Rockingham County that 15% of the dairy farms had dairy manure storage for less than 30 days; 10% of the dairy farms had storage capacities of 60 days, while the remaining operations had 180-day storage capacity. Using a decay rate of 0.375 for liquid dairy manure, the die-off of fecal coliform in different storage capacities at the ends of the respective storage periods were calculated using Eq. [5.1]. Based on the fractions of different storage capacities, a weighted average die-off was calculated for all dairy manure.

2. Based on fecal coliform die-off, the surviving fraction of fecal coliform at the end of storage period was estimated to be 0.0078 in dairy manure.

3. The annual production of fecal coliform based on ‘as-excreted’ values was calculated for dairy manure.

4. The annual fecal coliform production from dairy manure was multiplied by the fraction of surviving fecal coliform to obtain the amount of fecal coliform that was available for land application on annual basis. For monthly application, the annual figure was multiplied by the fraction of dairy applied during that month based on the application schedule given in Table 4.9.

APPENDIX D.
Weather Data Preparation

Weather Data Preparation

A weather data file for providing the weather data inputs into the HSPF Model was created for the period using WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi./h), total daily solar radiation (langleys), and percent sun. The primary data source for most parameters was the National Climatic Data Center's (NCDC) Cooperative Weather Station at Dale Enterprise, Rockingham Co., Virginia; data from three other NCDC stations were also used. Precipitation data were obtained primarily from the Biological Systems Engineering monitoring station, PLC, located in the Long Glade Run watershed. Locations and data periods from the stations used are listed in Table D-1. Daily solar radiation data was generated using WDMUtil. The raw data required varying amounts of preprocessing prior to input into WDMUtil or within WDMUtil to obtain the following hourly values: precipitation (PREC), air temperature (ATEM), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND), potential evapotranspiration (PEVT), potential evaporation (EVAP), and cloud cover (CLOU). The final WDM file contained the above hourly values as well as the raw data. Weather data in the variable length format were obtained from the NCDC's weather stations in Dale Enterprise, VA (Lat./Long. 38.5N/78.9W, elevation 1400 ft); Timberville, VA (Lat./Long. 38.7N/78.7W, elevation 1001 ft); Lynchburg Airport, VA (Lat./Long. 37.3N/79.2W, elevation 940 ft); and Elkins Airport, WV (Lat./Long. 38.9N/79.9W, elevation 1948 ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data.

Table D.1. Meteorological data sources.

Type of Data	Location	Source	Recording Frequency	Period of Record	Latitude Longitude
Rainfall (in)	Dale Enterprise	NCDC	1 Hour1 Day	1/1/73 – 12/31/998/1/48 – 12/31/01	38°10’52” 79°05’25”
Rainfall (in)	Timberville, VA	Local Resident	1 Day	1/1/84 – 12/31/01	38°10’52” 79°05’25”
Min Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 – 12/31/01	38°10’52” 79°05’25”
Max Air Temp (°F)	Staunton Sewage Treatment Plant	NCDC	1 Day	8/1/48 – 12/31/01	38°10’52” 79°05’25”
Min Air Temp (°F)	Dale Enterprise	NCDC	1 Day	8/1/48 – 12/31/01	38°27’19” 78°56’07”
Max Air Temp (°F)	Dale Enterprise	NCDC	1 Day	8/1/48 – 12/31/01	38°27’19” 78°56’07”
Cloud Cover (%)	Lynchburg Regional Airport	NCDC	1 Hour	8/1/48 – 12/31/01	37°20’15” 79°12’24”
Dew Point Temp (°F)	Lynchburg Regional Airport	NCDC	1 Hour	1/1/48 – 12/31/01	37°20’15” 79°12’24”
Wind Speed (360° and knots)	Elkins-Randolph Elkins WV	NCDC	1 Hour	1/1/64 – 12/31/01	38°53’07” 79°51’10”

APPENDIX E.
HSPF Parameters that Vary by Month or Land Use

Table E1. PWAT-PARM2 and PARM4 parameters that vary by land use for Mossy Creek.

Land Use	LZSN	LSUR	SLSUR	NSUR
	(in)	(ft)		
Crops	6	246	0.02	0.2
Pasture 1	6	242	0.03	0.4
Pasture 2	6	242	0.03	0.35
Loafing Lots	3	242	0.03	0.4
Farmstead	3.5	242	0.03	0.15
Low Density Residential	3.5	246	0.02	0.15
High Density Residential	3.5	246	0.02	0.15
Forest	6	238	0.04	0.45

Table E2. CEPSC (monthly interception storage capacity, inches) for Mossy Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.05	0.05	0.05	0.05	0.15	0.2	0.25	0.25	0.25	0.2	0.15	0.15
Pasture 1	0.05	0.05	0.05	0.05	0.05	0.25	0.25	0.25	0.05	0.05	0.05	0.05
Pasture 2	0.05	0.05	0.05	0.05	0.05	0.25	0.25	0.25	0.05	0.05	0.05	0.05
Loafing Lots	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Farmstead	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Low Density Residential	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
High Density Residential	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Forest	0.05	0.05	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.15	0.05	0.05

Table E3. UZSN (monthly upper zone storage, inches) for Mossy Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.01	0.01	0.1	0.15	0.1	0.75	0.75	0.75	0.7	0.4	0.15	0.01
Pasture 1	0.01	0.01	0.2	0.3	0.5	1	1	1	1	0.7	0.3	0.01
Pasture 2	0.01	0.01	0.2	0.3	0.35	0.8	0.8	0.8	0.7	0.7	0.2	0.01
Loafing Lots	0.01	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.01
Farmstead	0.01	0.01	0.07	0.07	0.1	0.3	0.3	0.3	0.1	0.1	0.1	0.01
Low Density Residential	0.01	0.01	0.07	0.07	0.1	0.3	0.3	0.3	0.1	0.1	0.1	0.01
High Density Residential	0.01	0.01	0.07	0.07	0.1	0.3	0.3	0.3	0.1	0.1	0.1	0.01
Forest	0.02	0.02	0.1	0.2	0.3	0.9	0.9	0.9	0.7	0.4	0.1	0.02

Table E4. LZETP (monthly lower zone evapotranspiration factor) for Mossy Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.05	0.05	0.1	0.15	0.3	0.6	0.6	0.6	0.6	0.3	0.15	0.05
Pasture 1	0.05	0.05	0.2	0.3	0.4	0.7	0.7	0.7	0.6	0.3	0.2	0.05
Pasture 2	0.05	0.05	0.15	0.25	0.3	0.6	0.6	0.6	0.5	0.2	0.15	0.05
Loafing Lots	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Farmstead	0.05	0.05	0.05	0.2	0.3	0.4	0.4	0.4	0.3	0.2	0.15	0.05
Low Density Residential	0.05	0.05	0.05	0.2	0.3	0.4	0.4	0.4	0.3	0.2	0.15	0.05
High Density Residential	0.05	0.05	0.05	0.2	0.3	0.4	0.4	0.4	0.3	0.2	0.15	0.05
Forest	0.05	0.05	0.3	0.35	0.4	0.8	0.8	0.8	0.7	0.5	0.3	0.05

Table E5. ACQOP (monthly accumulation rate for fecal coliform) for Mossy Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
*** MC-1												
Crops	2.00E+07	5.00E+08	2.00E+09	2.00E+09	5.00E+08	2.00E+07	2.00E+07	2.00E+07	2.00E+07	5.00E+08	8.00E+08	2.00E+07
Pasture 1	1.00E+10	1.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	2.00E+10	2.00E+10	1.00E+10
Pasture 2	6.00E+09	7.00E+09	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	6.00E+09
Farmstead	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Loafing Lot	2.00E+11	2.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	4.00E+11	4.00E+11	4.00E+11	3.00E+11	3.00E+11	1.00E+11
Forest	2.00E+08	2.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
*** MC-2												
Crops	2.00E+07	7.00E+08	3.00E+09	3.00E+09	7.00E+08	2.00E+07	2.00E+07	2.00E+07	2.00E+07	9.00E+08	1.00E+09	2.00E+07
Pasture 1	1.00E+10	2.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	2.00E+10	2.00E+10	1.00E+10
Pasture 2	7.00E+09	8.00E+09	1.00E+10	1.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10	1.00E+10	7.00E+09
Urban	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09
LDR	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09
HDR	1.00E+12	1.00E+12	2.00E+12	2.00E+12	2.00E+12	3.00E+12	3.00E+12	3.00E+12	3.00E+12	2.00E+12	2.00E+12	1.00E+12
Forest	2.00E+08	2.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
*** MC-3												
Crops	2.00E+07	2.00E+09	8.00E+09	6.00E+09	2.00E+09	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+09	2.00E+09	2.00E+07
Pasture 1	1.00E+10	2.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	2.00E+10	2.00E+10	1.00E+10
Pasture 2	3.00E+10	3.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	4.00E+10	3.00E+10	3.00E+10	3.00E+10
Farmstead	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
Forest	1.00E+08	1.00E+08	8.00E+07	8.00E+07	8.00E+07	8.00E+07	8.00E+07	8.00E+07	1.00E+08	1.00E+08	1.00E+08	1.00E+08
*** MC-4												
Crops	2.00E+07	5.00E+08	2.00E+09	2.00E+09	4.00E+08	2.00E+07	2.00E+07	2.00E+07	2.00E+07	5.00E+08	6.00E+08	2.00E+07
Pasture 1	2.00E+10	2.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	4.00E+10	4.00E+10	4.00E+10	3.00E+10	3.00E+10	2.00E+10
Pasture 2	8.00E+09	1.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10	1.00E+10	8.00E+09
Farmstead	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
LDR	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09
Forest	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+07

*** MC-5												
Crops	2.00E+07	2.00E+09	8.00E+09	6.00E+09	2.00E+09	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+09	2.00E+09	2.00E+07
Pasture 1	1.00E+10	1.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	2.00E+10	2.00E+10	1.00E+10
Pasture 2	6.00E+09	7.00E+09	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	9.00E+09	9.00E+09	6.00E+09
Farmstead	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08
LDR	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08
Forest	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08
*** MC-6												
Crops	2.00E+07	6.00E+08	3.00E+09	2.00E+09	6.00E+08	2.00E+07	2.00E+07	2.00E+07	2.00E+07	6.00E+08	9.00E+08	2.00E+07
Pasture 1	2.00E+10	2.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	4.00E+10	2.00E+10	2.00E+10	2.00E+10
Pasture 2	1.00E+10	1.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10
Farmstead	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09
LDR	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09	6.00E+09
HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Forest	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08
*** B09-7												
Crops	2.00E+07	6.00E+08	3.00E+09	2.00E+09	6.00E+08	2.00E+07	2.00E+07	2.00E+07	2.00E+07	5.00E+08	9.00E+08	2.00E+07
Pasture 1	1.00E+10	2.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	4.00E+10	3.00E+10	3.00E+10	1.00E+10
Pasture 2	7.00E+09	9.00E+09	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10	1.00E+10	7.00E+09
Farmstead	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08
LDR	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08
Forest	3.00E+08	3.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08
*** B09-8												
Crops	2.00E+07	2.00E+09	7.00E+09	6.00E+09	2.00E+09	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.00E+09	2.00E+09	2.00E+07
Pasture 1	1.00E+10	2.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	2.00E+10	2.00E+10	1.00E+10
Pasture 2	1.00E+10	1.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10	1.00E+10	1.00E+10
Farmstead	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09
LDR	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09
Forest	1.00E+08	1.00E+08	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	7.00E+07	1.00E+08	1.00E+08	1.00E+08	1.00E+08

Table E6. SQOLIM Table for Mossy Creek

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
*** MC-1												
Crops	2.00E+08	5.00E+09	2.00E+10	2.00E+10	5.00E+09	2.00E+08	2.00E+08	2.00E+08	2.00E+08	5.00E+09	7.00E+09	2.00E+08

Pasture 1	9.00E+10	9.00E+10	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	2.00E+11	2.00E+11	9.00E+10
Pasture 2	5.00E+10	6.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	5.00E+10
Farmstead	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
LDR	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Loafing Lot	2.00E+12	2.00E+12	3.00E+12	3.00E+12	3.00E+12	3.00E+12	4.00E+12	4.00E+12	4.00E+12	3.00E+12	3.00E+12	9.00E+11
Forest	2.00E+09	2.00E+09	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	2.00E+09	2.00E+09	2.00E+09	2.00E+09
*** MC-2												
Crops	2.00E+08	6.00E+09	3.00E+10	3.00E+10	6.00E+09	2.00E+08	2.00E+08	2.00E+08	2.00E+08	8.00E+09	9.00E+09	2.00E+08
Pasture 1	9.00E+10	2.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	2.00E+11	2.00E+11	9.00E+10
Pasture 2	6.00E+10	7.00E+10	9.00E+10	9.00E+10	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	9.00E+10	9.00E+10	6.00E+10
Urban	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10
LDR	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10
HDR	9.00E+12	9.00E+12	2.00E+13	2.00E+13	2.00E+13	3.00E+13	3.00E+13	3.00E+13	3.00E+13	2.00E+13	2.00E+13	9.00E+12
Forest	2.00E+09	2.00E+09	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	2.00E+09	2.00E+09	2.00E+09	2.00E+09
*** MC-3												
Crops	2.00E+08	2.00E+10	7.00E+10	5.00E+10	2.00E+10	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+10	2.00E+10	2.00E+08
Pasture 1	9.00E+10	2.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	2.00E+11	2.00E+11	9.00E+10
Pasture 2	3.00E+11	3.00E+11	4.00E+11	4.00E+11	4.00E+11	4.00E+11	4.00E+11	4.00E+11	4.00E+11	3.00E+11	3.00E+11	3.00E+11
Farmstead	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
LDR	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
Forest	9.00E+08	9.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	7.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08
*** MC-4												
Crops	2.00E+08	5.00E+09	2.00E+10	2.00E+10	4.00E+09	2.00E+08	2.00E+08	2.00E+08	2.00E+08	5.00E+09	5.00E+09	2.00E+08
Pasture 1	2.00E+11	2.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	4.00E+11	4.00E+11	4.00E+11	3.00E+11	3.00E+11	2.00E+11
Pasture 2	7.00E+10	9.00E+10	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	9.00E+10	9.00E+10	7.00E+10
Farmstead	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
LDR	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
Forest	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+08
*** MC-5												
Crops	2.00E+08	2.00E+10	7.00E+10	5.00E+10	2.00E+10	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+10	2.00E+10	2.00E+08
Pasture 1	9.00E+10	9.00E+10	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	2.00E+11	2.00E+11	9.00E+10
Pasture 2	5.00E+10	6.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	9.00E+10	8.00E+10	8.00E+10	5.00E+10

Farmstead	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09
LDR	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09	4.00E+09
Forest	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08
*** MC-6												
Crops	2.00E+08	5.00E+09	3.00E+10	2.00E+10	5.00E+09	2.00E+08	2.00E+08	2.00E+08	2.00E+08	5.00E+09	8.00E+09	2.00E+08
Pasture 1	2.00E+11	2.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	4.00E+11	2.00E+11	2.00E+11	2.00E+11
Pasture 2	9.00E+10	9.00E+10	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	9.00E+10
Farmstead	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10
LDR	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10	5.00E+10
HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Forest	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08
*** MC-7												
Crops	2.00E+08	5.00E+09	3.00E+10	2.00E+10	5.00E+09	2.00E+08	2.00E+08	2.00E+08	2.00E+08	5.00E+09	8.00E+09	2.00E+08
Pasture 1	9.00E+10	2.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	4.00E+11	3.00E+11	3.00E+11	9.00E+10
Pasture 2	6.00E+10	8.00E+10	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	9.00E+10	9.00E+10	6.00E+10
Farmstead	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09
LDR	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09	7.00E+09
Forest	3.00E+09	3.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	2.00E+09	3.00E+09	3.00E+09	3.00E+09	3.00E+09
*** MC-8												
Crops	2.00E+08	2.00E+10	6.00E+10	5.00E+10	2.00E+10	2.00E+08	2.00E+08	2.00E+08	2.00E+08	2.00E+10	2.00E+10	2.00E+08
Pasture 1	9.00E+10	2.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	3.00E+11	2.00E+11	2.00E+11	9.00E+10
Pasture 2	9.00E+10	9.00E+10	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	2.00E+11	9.00E+10	9.00E+10	9.00E+10
Farmstead	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10
LDR	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10
Forest	9.00E+08	9.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	6.00E+08	9.00E+08	9.00E+08	9.00E+08	9.00E+08

Table E7. Land use varying PWAT-PARM2 and PARM4 parameters for Long Glade Run

Land Use	LZSN (in)	INFILT (in/hr)	LSUR (ft)	SLSUR	AGWRC (1/day)	NSUR
Crops	10.15	0.18	246	0.08	0.99	0.2
Pasture 1	10.15	0.18	242	0.083	0.99	0.4
Pasture 2	10.15	0.18	242	0.078	0.99	0.35
Loafing Lots	7.15	0.08	242	0.085	0.94	0.4
Farmstead	9.15	0.16	242	0.065	0.96	0.15
Low Density Residential	8.15	0.12	246	0.084	0.96	0.15
High Density Residential	5.15	0.12	246	0.074	0.96	0.15
Forest	10.15	0.18	238	0.099	0.99	0.45

Table E8. CEPSC (monthly interception storage capacity, inches) for Long Glade Run

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.05	0.05	0.05	0.05	0.15	0.2	0.25	0.25	0.25	0.2	0.15	0.15
Pasture 1	0.05	0.05	0.05	0.05	0.05	0.25	0.25	0.25	0.05	0.05	0.05	0.05
Pasture 2	0.05	0.05	0.05	0.05	0.05	0.25	0.25	0.25	0.05	0.05	0.05	0.05
Loafing Lots	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Farmstead	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Low Density Residential	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
High Density Residential	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Forest	0.05	0.05	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.15	0.05	0.05

Table E9. LZETP (monthly lower zone evapotranspiration factor) for Long Glade Run

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Crops	0.05	0.05	0.10	0.15	0.30	0.80	0.80	0.80	0.60	0.30	0.15	0.05
Pasture 1	0.05	0.05	0.2	0.3	0.4	0.75	0.75	0.75	0.6	0.3	0.2	0.05
Pasture 2	0.05	0.05	0.15	0.25	0.3	0.7	0.7	0.7	0.5	0.2	0.15	0.05
Loafing Lots	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Farmstead	0.05	0.05	0.05	0.2	0.3	0.5	0.5	0.5	0.3	0.2	0.15	0.05
Low Density Residential	0.05	0.05	0.05	0.2	0.3	0.5	0.5	0.5	0.3	0.2	0.15	0.05
High Density Residential	0.05	0.05	0.05	0.2	0.3	0.5	0.5	0.5	0.3	0.2	0.15	0.05
Forest	0.05	0.05	0.3	0.35	0.4	0.9	0.9	0.9	0.8	0.5	0.3	0.05

Table E10. ACQOP (monthly accumulation rate for fecal coliform) for Long Glade Run

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
***LG-1												
Crops	1.E+07	2.E+09	8.E+09	6.E+09	2.E+09	1.E+07	1.E+07	1.E+07	1.E+07	2.E+09	2.E+09	1.E+07
Pasture 1	9.E+09	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10	2.E+10	9.E+09
Pasture 2	5.E+09	5.E+09	9.E+09	9.E+09	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	7.E+09	7.E+09	5.E+09
Farmstead	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09
LDR	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09
HDR	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
Forest	5.E+08	5.E+08	3.E+08	3.E+08	3.E+08	3.E+08	3.E+08	3.E+08	5.E+08	5.E+08	5.E+08	5.E+08
***LG-2												
Crops	1.E+07	1.E+09	4.E+09	4.E+09	9.E+08	1.E+07	1.E+07	1.E+07	1.E+07	1.E+09	1.E+09	1.E+07
Pasture 1	9.E+09	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10	1.E+10	9.E+09
Pasture 2	5.E+09	5.E+09	9.E+09	9.E+09	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	7.E+09	7.E+09	5.E+09
Farmstead	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09	5.E+09
Forest	4.E+08	4.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	4.E+08	4.E+08	4.E+08	4.E+08
***LG-3												
Crops	1.E+07	5.E+08	2.E+09	2.E+09	4.E+08	1.E+07	1.E+07	1.E+07	1.E+07	5.E+08	7.E+08	1.E+07
Pasture 1	1.E+10	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	3.E+10	2.E+10	2.E+10	1.E+10
Pasture 2	6.E+09	7.E+09	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	9.E+09	9.E+09	6.E+09
Farmstead	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09
LDR	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09
HDR	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
Forest	2.E+08	2.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	2.E+08	2.E+08	2.E+08	2.E+08
***LG-4												
Crops	1.E+07	1.E+09	6.E+09	5.E+09	1.E+09	1.E+07	1.E+07	1.E+07	1.E+07	2.E+09	2.E+09	1.E+07
Pasture 1	1.E+10	2.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	2.E+10	1.E+10
Pasture 2	7.E+09	8.E+09	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10	1.E+10	7.E+09
Farmstead	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08
LDR	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08	4.E+08
Forest	3.E+07	3.E+07	2.E+07	2.E+07	2.E+07	2.E+07	2.E+07	2.E+07	3.E+07	3.E+07	3.E+07	3.E+07
***LG-5												

Crops	2.E+07	6.E+08	3.E+09	2.E+09	6.E+08	2.E+07	2.E+07	2.E+07	2.E+07	8.E+08	9.E+08	2.E+07
Pasture 1	9.E+09	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10	1.E+10	9.E+09
Pasture 2	5.E+09	5.E+09	9.E+09	9.E+09	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	7.E+09	7.E+09	5.E+09
Farmstead	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08
Forest	3.E+08	3.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	3.E+08	3.E+08	3.E+08	3.E+08
***LG-6												
Crops	1.E+07	7.E+08	3.E+09	3.E+09	6.E+08	1.E+07	1.E+07	1.E+07	1.E+07	9.E+08	1.E+09	1.E+07
Pasture 1	1.E+10	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10
Pasture 2	6.E+09	7.E+09	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	9.E+09	9.E+09	6.E+09
Farmstead	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09
LDR	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09
Loafing Lot	1.E+11	1.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	1.E+11
Forest	2.E+08	2.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	2.E+08	2.E+08	2.E+08	2.E+08
***LG-7												
Crops	1.E+07	1.E+09	5.E+09	4.E+09	1.E+09	1.E+07	1.E+07	1.E+07	1.E+07	1.E+09	2.E+09	1.E+07
Pasture 1	1.E+10	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10	1.E+10	1.E+10
Pasture 2	1.E+10	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10	1.E+10	1.E+10
Farmstead	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09
LDR	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09	3.E+09
Forest	2.E+08	2.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	2.E+08	2.E+08	2.E+08	2.E+08
***LG-8												
Crops	1.E+07	7.E+08	3.E+09	3.E+09	6.E+08	1.E+07	1.E+07	1.E+07	1.E+07	1.E+09	1.E+09	1.E+07
Pasture 1	9.E+09	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10	2.E+10	9.E+09
Pasture 2	6.E+09	7.E+09	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	9.E+09	9.E+09	6.E+09
Farmstead	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09
LDR	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09
Forest	5.E+07	5.E+07	4.E+07	4.E+07	4.E+07	4.E+07	4.E+07	4.E+07	5.E+07	5.E+07	5.E+07	5.E+07

***LG-9												
Crops	1.E+07	2.E+09	7.E+09	6.E+09	1.E+09	1.E+07	1.E+07	1.E+07	1.E+07	2.E+09	2.E+09	1.E+07
Pasture 1	1.E+10	1.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	1.E+10
Pasture 2	2.E+10	2.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	2.E+10	2.E+10	2.E+10

Farmstead	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09
LDR	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09	4.E+09
Forest	6.E+07	6.E+07	4.E+07	4.E+07	4.E+07	4.E+07	4.E+07	4.E+07	6.E+07	6.E+07	6.E+07	6.E+07

Table E11. SQOLIM Table for Long Glade Run

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
***LG-1												
Crops	6.E+07	1.E+10	4.E+10	3.E+10	1.E+10	6.E+07	6.E+07	6.E+07	6.E+07	1.E+10	1.E+10	6.E+07
Pasture 1	5.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10	1.E+11	5.E+10
Pasture 2	3.E+10	3.E+10	5.E+10	5.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	4.E+10	4.E+10	3.E+10
Farmstead	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10
LDR	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10
HDR	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01
Forest	3.E+09	3.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	3.E+09	3.E+09	3.E+09	3.E+09
***LG-2												
Crops	6.E+07	6.E+09	2.E+10	2.E+10	5.E+09	6.E+07	6.E+07	6.E+07	6.E+07	6.E+09	6.E+09	6.E+07
Pasture 1	5.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10	6.E+10	5.E+10
Pasture 2	3.E+10	3.E+10	5.E+10	5.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	4.E+10	4.E+10	3.E+10
Farmstead	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10	3.E+10
Forest	2.E+09	2.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	2.E+09	2.E+09	2.E+09	2.E+09
***LG-3												
Crops	6.E+07	3.E+09	1.E+10	1.E+10	2.E+09	6.E+07	6.E+07	6.E+07	6.E+07	3.E+09	4.E+09	6.E+07
Pasture 1	6.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	2.E+11	1.E+11	1.E+11	6.E+10
Pasture 2	3.E+10	4.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	5.E+10	5.E+10	3.E+10
Farmstead	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09
LDR	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09	6.E+09
HDR	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01	1.E-01
Forest	1.E+09	1.E+09	6.E+08	6.E+08	6.E+08	6.E+08	6.E+08	6.E+08	1.E+09	1.E+09	1.E+09	1.E+09
***LG-4												
Crops	6.E+07	6.E+09	3.E+10	3.E+10	6.E+09	6.E+07	6.E+07	6.E+07	6.E+07	1.E+10	1.E+10	6.E+07
Pasture 1	6.E+10	1.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	1.E+11	6.E+10
Pasture 2	4.E+10	4.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10	6.E+10	4.E+10

Farmstead	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09
LDR	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09	2.E+09
Forest	2.E+08	2.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	1.E+08	2.E+08	2.E+08	2.E+08	2.E+08
***LG-5												
Crops	1.E+08	3.E+09	2.E+10	1.E+10	3.E+09	1.E+08	1.E+08	1.E+08	1.E+08	4.E+09	5.E+09	1.E+08
Pasture 1	5.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10	6.E+10	5.E+10
Pasture 2	3.E+10	3.E+10	5.E+10	5.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	4.E+10	4.E+10	3.E+10
Farmstead	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09
Forest	2.E+09	2.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	1.E+09	2.E+09	2.E+09	2.E+09	2.E+09
***LG-6												
Crops	6.E+07	4.E+09	2.E+10	2.E+10	3.E+09	6.E+07	6.E+07	6.E+07	6.E+07	5.E+09	6.E+09	6.E+07
Pasture 1	6.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10
Pasture 2	3.E+10	4.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	5.E+10	5.E+10	3.E+10
Farmstead	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10
LDR	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10
Loafing Lot	6.E+11	6.E+11	1.E+12	1.E+12	1.E+12	1.E+12	1.E+12	1.E+12	1.E+12	1.E+12	1.E+12	6.E+11
Forest	1.E+09	1.E+09	6.E+08	6.E+08	6.E+08	6.E+08	6.E+08	6.E+08	1.E+09	1.E+09	1.E+09	1.E+09
***LG-7												
Crops	6.E+07	6.E+09	3.E+10	2.E+10	6.E+09	6.E+07	6.E+07	6.E+07	6.E+07	6.E+09	1.E+10	6.E+07
Pasture 1	6.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10	6.E+10	6.E+10
Pasture 2	6.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10	6.E+10	6.E+10
Farmstead	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10
LDR	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10
Forest	1.E+09	1.E+09	6.E+08	6.E+08	6.E+08	6.E+08	6.E+08	6.E+08	1.E+09	1.E+09	1.E+09	1.E+09
***LG-8												
Crops	6.E+07	4.E+09	2.E+10	2.E+10	3.E+09	6.E+07	6.E+07	6.E+07	6.E+07	6.E+09	6.E+09	6.E+07
Pasture 1	5.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10	1.E+11	5.E+10
Pasture 2	3.E+10	4.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	6.E+10	5.E+10	5.E+10	3.E+10
Farmstead	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10
LDR	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10	1.E+10
Forest	3.E+08	3.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	3.E+08	3.E+08	3.E+08	3.E+08
***LG-9												

Crops	6.E+07	1.E+10	4.E+10	3.E+10	6.E+09	6.E+07	6.E+07	6.E+07	6.E+07	1.E+10	1.E+10	6.E+07
Pasture 1	6.E+10	6.E+10	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	1.E+11	6.E+10
Pasture 2	1.E+11	1.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	2.E+11	1.E+11	1.E+11	1.E+11
Farmstead	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10
LDR	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10	2.E+10
Forest	3.E+08	3.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	2.E+08	3.E+08	3.E+08	3.E+08	3.E+08

APPENDIX F.
Fecal Coliform Loading in Sub-Watersheds

Table F.1. Monthly nonpoint fecal coliform loadings in sub-watershed MC-01.

Month	Fecal Coliform loadings (x10^10 cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	15,107	154	0	93	230	1,814
Feb.	96	16,263	162	0	85	210	1,891
Mar.	467	32,585	314	0	67	230	3,773
Apr.	374	32,445	316	0	65	222	3,855
May	96	33,129	335	0	67	230	4,071
Jun.	4	32,807	331	0	65	222	4,024
Jul.	4	34,664	350	0	67	230	4,245
Aug.	4	35,440	358	0	67	230	4,333
Sep.	4	35,450	354	0	90	222	4,277
Oct.	97	24,384	241	0	93	230	3,047
Nov.	144	24,087	238	0	90	222	2,934
Dec.	4	14,525	148	0	93	230	1,748
Total	1,297	330,887	3,303	0	941	2,709	40,012

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.2. Monthly nonpoint fecal coliform loadings in sub-watershed MC-02.

Month	Fecal Coliform loadings (x10^10 cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	8	18,369	692	0	103	230	2,022
Feb.	302	18,957	713	0	94	210	2,095
Mar.	1,480	36,781	1,378	0	77	230	4,241
Apr.	1,185	36,974	1,387	0	75	222	4,361
May	302	38,872	1,463	0	77	230	4,599
Jun.	8	38,308	1,441	0	75	222	4,540
Jul.	8	40,379	1,519	0	77	230	4,783
Aug.	8	41,175	1,549	0	77	230	4,875
Sep.	8	40,741	1,531	0	100	222	4,807
Oct.	390	29,556	1,111	0	103	230	3,517
Nov.	456	28,931	1,087	0	100	222	3,347
Dec.	8	17,770	670	0	103	230	1,953
Total	4,163	386,814	14,542	0	1,062	2,709	45,139

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.3. Monthly nonpoint fecal coliform loadings in sub-watershed MC-03.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	21,968	1,104	0	101	224	0
Feb.	451	23,859	1,039	0	92	204	0
Mar.	2,237	45,727	1,317	0	75	224	0
Apr.	1,790	44,908	1,286	0	72	217	0
May	452	45,759	1,341	0	75	224	0
Jun.	5	45,320	1,308	0	72	217	0
Jul.	5	48,000	1,363	0	75	224	0
Aug.	5	49,,189	1,376	0	75	224	0
Sep.	5	49493	1,344	0	98	217	0
Oct.	684	32,350	1,198	0	101	224	0
Nov.	684	32,799	1,174	0	98	217	0
Dec.	5	21,072	1,094	0	101	224	0
Total	6,330	460,445	14,943	0	1,033	2,639	0

[1] Includes Farmstead, Low and High Density Residential Loads
, Low and High Density Residential Loads

Table F.4. Monthly nonpoint fecal coliform loadings in sub-watershed MC-04.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	15,360	320	0	5.3	62	0
Feb.	86	16,054	341	0	4.8	57	0
Mar.	415	31,475	685	0	5.3	62	0
Apr.	332	31,161	673	0	5.1	60	0
May	86	31,969	672	0	5.3	62	0
Jun.	4	31,575	664	0	5.1	60	0
Jul.	4	33,267	699	0	5.3	62	0
Aug.	4	33,917	713	0	5.3	62	0
Sep.	4	33,741	715	0	5.1	60	0
Oct.	104	24,619	525	0	5.3	62	0
Nov.	129	24,320	519	0	5.1	60	0
Dec.	4	14,873	310	0	5.3	62	0
Total	1,173	322,331	6,836	0	62	734	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.5. Monthly nonpoint fecal coliform loadings in sub-watershed MC-05.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	11	19,050	96	0	119	52	0
Feb.	933	20,992	103	0	108	48	0
Mar.	4,628	41,418	194	0	84	52	0
Apr.	3,704	40,616	193	0	82	50	0
May	934	41,104	205	0	84	52	0
Jun.	11	40,738	203	0	82	50	0
Jul.	11	43,173	215	0	84	52	0
Aug.	11	44,270	221	0	84	52	0
Sep.	11	44,677	220	0	115	50	0
Oct.	1,416	28,809	139	0	119	52	0
Nov.	1,416	29,263	142	0	115	50	0
Dec.	11	18,224	92	0	119	52	0
Total	13,097	412,334	2,022	0	1,196	615	0

[1] Includes Farmstead, Low and High Density Residential Loads
Farmstead, Low and High Density Residential Loads

Table F.6. Monthly nonpoint fecal coliform loadings in sub-watershed MC-06.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	13	63,528	5,645	0	259	619	0
Feb.	415	66,460	5,623	0	236	564	0
Mar.	2,027	128,477	9,407	0	190	619	0
Apr.	1,624	128,168	9,383	0	184	599	0
May	416	132,526	9,859	0	190	619	0
Jun.	13	130,242	9,662	0	184	599	0
Jul.	13	137,367	10,158	0	190	619	0
Aug.	13	140,177	10,331	0	190	619	0
Sep.	13	140,036	10,217	0	251	599	0
Oct.	470	100,262	7,814	0	259	619	0
Nov.	626	98,711	7,663	0	251	599	0
Dec.	13	61,401	5,514	0	259	619	0
Total	5,658	1,327,356	101,276	0	2,641	7,287	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.7. Monthly nonpoint fecal coliform loadings in sub-watershed MC-07.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	12,610	1,994	0	81	212	0
Feb.	99	13,352	2,070	0	74	193	0
Mar.	481	27,035	4,068	0	57	212	0
Apr.	385	27,156	4,128	0	55	205	0
May	99	27,828	4,356	0	57	212	0
Jun.	4	27,465	4,299	0	55	205	0
Jul.	4	28,957	4,534	0	57	212	0
Aug.	4	29,542	4,627	0	57	212	0
Sep.	4	29,465	4,574	0	78	205	0
Oct.	90	21,209	3,270	0	81	212	0
Nov.	149	20,607	3,175	0	78	205	0
Dec.	4	12,170	1,924	0	81	212	0
Total	1,324	277,394	43,018	0	810	2,497	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.8. Monthly nonpoint fecal coliform loadings in sub-watershed MC-08.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	29	65,361	4,334	0	248	545	0
Feb.	2,393	69,945	4,351	0	226	497	0
Mar.	11,862	134,483	7,090	0	187	545	0
Apr.	9,494	133,038	7,029	0	181	528	0
May	2,395	137,043	7,401	0	187	545	0
Jun.	28	135,058	7,266	0	181	528	0
Jul.	29	142,867	7,654	0	187	545	0
Aug.	29	146,213	7,799	0	187	545	0
Sep.	28	146,840	7,729	0	240	528	0
Oct.	3,573	98,768	5,687	0	248	545	0
Nov.	3,629	99,125	5,654	0	240	528	0
Dec.	29	62,827	4,224	0	248	545	0
Total	33,515	1,371,567	76,219	0	2,559	6,424	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.9. Monthly nonpoint fecal coliform loadings in sub-watershed LG-01.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	8,564	698	0	52	242	0
Feb.	190	9,935	747	0	47	220	0
Mar.	942	21,117	1,404	0	35	242	0
Apr.	754	20,263	1,398	0	34	234	0
May	190	19,000	1,485	0	35	242	0
Jun.	2	18,883	1,475	0	34	234	0
Jul.	2	19,982	1,564	0	35	242	0
Aug.	2	20,477	1,605	0	35	242	0
Sep.	2	21,107	1,593	0	50	234	0
Oct.	288	13,956	1,011	0	52	242	0
Nov.	288	14,156	1,027	0	50	234	0
Dec.	2	8,564	698	0	52	242	0
Total	2,661	196,004	14,704	0	511	2,850	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.10. Monthly nonpoint fecal coliform loadings in sub-watershed LG-02.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	7,172	537	0	42	140	0
Feb.	81	7,670	574	0	38	128	0
Mar.	400	14,428	1,079	0	25	140	0
Apr.	320	14,361	1,074	0	24	136	0
May	81	15,247	1,140	0	25	140	0
Jun.	1	15,129	1,131	0	24	136	0
Jul.	1	16,047	1,200	0	25	140	0
Aug.	1	16,461	1,231	0	25	140	0
Sep.	1	16,360	1,223	0	40	136	0
Oct.	123	10,382	777	0	42	140	0
Nov.	123	10,551	789	0	40	136	0
Dec.	1	7,172	537	0	42	140	0
Total	1,135	150,979	11,294	0	390	1,650	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.11. Monthly nonpoint fecal coliform loadings in sub-watershed LG-03.

Month	Fecal Coliform loadings (x10^10 cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	11,748	1,713	0	108	173	0
Feb.	147	12,614	1,757	0	99	157	0
Mar.	719	25,406	3,209	0	72	173	0
Apr.	576	25,382	3,240	0	70	167	0
May	148	25,725	3,418	0	72	173	0
Jun.	5	25,387	3,368	0	70	167	0
Jul.	5	26,794	3,551	0	72	173	0
Aug.	5	27,366	3,623	0	72	173	0
Sep.	5	27,464	3,585	0	105	167	0
Oct.	175	19,339	2,577	0	108	173	0
Nov.	222	18,905	2,515	0	105	167	0
Dec.	5	11,748	1,713	0	108	173	0
Total	2,017	257,880	34,268	0	1,062	2,035	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.12. Monthly nonpoint fecal coliform loadings in sub-watershed LG-04.

Month	Fecal Coliform loadings (x10^10 cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	10	25,277	391	0	8	101	0
Feb.	774	26,087	396	0	8	92	0
Mar.	3,834	53,622	790	0	6	101	0
Apr.	3,069	54,127	805	0	6	98	0
May	775	55,233	847	0	6	101	0
Jun.	9	54,365	833	0	6	98	0
Jul.	10	57,087	875	0	6	101	0
Aug.	10	58,014	890	0	6	101	0
Sep.	9	57,575	875	0	8	98	0
Oct.	1,032	44,862	678	0	8	101	0
Nov.	1,173	42,797	646	0	8	98	0
Dec.	10	25,277	391	0	8	101	0
Total	10,714	554,322	8,416	0	84	1,190	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.13. Monthly nonpoint fecal coliform loadings in sub-watershed LG-05.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	2,601	83	0	44	1.4	0
Feb.	66	2,782	89	0	40	1.3	0
Mar.	321	5,233	167	0	35	1.4	0
Apr.	257	5,207	166	0	34	1.4	0
May	66	5,525	176	0	35	1.4	0
Jun.	2	5,469	175	0	34	1.4	0
Jul.	2	5,801	185	0	35	1.4	0
Aug.	2	5,950	190	0	35	1.4	0
Sep.	2	5,928	189	0	43	1.4	0
Oct.	99	3,764	120	0	44	1.4	0
Nov.	99	3,826	122	0	43	1.4	0
Dec.	2	2,601	83	0	44	1.4	0
Total	920	54,687	1,747	0	465	16	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.14. Monthly nonpoint fecal coliform loadings in sub-watershed LG-06.

Month	Fecal Coliform loadings (x10^{10} cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	21	48,447	2,653	0	228	283	5,246
Feb.	953	49,865	2,700	0	208	258	5,447
Mar.	4,692	95,376	4,973	0	170	283	10,729
Apr.	3,757	95,581	4,975	0	164	274	10,955
May	955	100,813	5,242	0	170	283	11,564
Jun.	20	99,410	5,164	0	164	274	11,427
Jul.	21	104,809	5,440	0	170	283	12,052
Aug.	21	106,894	5,543	0	170	283	12,296
Sep.	20	105,647	5,473	0	221	274	12,135
Oct.	1,310	76,303	4,030	0	228	283	8,699
Nov.	1,442	75,106	3,963	0	221	274	8,377
Dec.	21	48,447	2,653	0	228	283	5,246
Total	13,232	1,006,698	52,807	0	2,341	,3331	114,174

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.15. Monthly nonpoint fecal coliform loadings in sub-watershed LG-07.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	32,088	3,325	0	159	254	0
Feb.	311	33,802	3,255	0	144	231	0
Mar.	1,539	61,904	4,799	0	120	254	0
Apr.	1,232	61,682	4,732	0	116	246	0
May	311	65,367	4,970	0	120	254	0
Jun.	4	64,723	4,883	0	116	246	0
Jul.	4	68,542	5,127	0	120	254	0
Aug.	4	70,204	5,210	0	120	254	0
Sep.	4	69,707	5,129	0	153	246	0
Oct.	457	45,819	4,004	0	159	254	0
Nov.	471	46,192	3,966	0	153	246	0
Dec.	4	32,088	3,325	0	159	254	0
Total	4,347	652,118	52,725	0	1,638	2,991	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.16. Monthly nonpoint fecal coliform loadings in sub-watershed LG-08.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	11	30,053	4,560	0	136	192	0
Feb.	514	33,734	5,177	0	124	175	0
Mar.	2,533	68,110	10,458	0	107	192	0
Apr.	2,028	65,967	9,936	0	104	186	0
May	515	64,068	9,040	0	107	192	0
Jun.	11	63,531	8,947	0	104	186	0
Jul.	11	67,236	9,436	0	107	192	0
Aug.	11	68,885	9,643	0	107	192	0
Sep.	11	70,282	10,019	0	132	186	0
Oct.	778	46,500	7,073	0	136	192	0
Nov.	778	47,129	7,125	0	132	186	0
Dec.	11	30,053	4,560	0	136	192	0
Total	7,213	655,549	95,976	0	1,431	2,261	0

[1] Includes Farmstead, Low and High Density Residential Loads

Table F.17. Monthly nonpoint fecal coliform loadings in sub-watershed LG-09.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	10	49,803	6,861	0	126	360	0
Feb.	1,070	51,701	6,480	0	115	328	0
Mar.	5,317	92,964	8,433	0	97	360	0
Apr.	4,255	92,208	8,254	0	94	348	0
May	1,071	96,616	8,612	0	97	360	0
Jun.	9	95,646	8,415	0	94	348	0
Jul.	10	101,033	8,779	0	97	360	0
Aug.	10	103,242	8,862	0	97	360	0
Sep.	9	102,336	8,656	0	122	348	0
Oct.	1,597	70,946	7,636	0	126	360	0
Nov.	1,624	71,008	7,477	0	122	348	0
Dec.	10	49,803	6,861	0	126	360	0
Total	14,992	977,307	95,327	0	1,310	4,238	0

[1] Includes Farmstead, Low and High Density Residential Loads

APPENDIX G.
Required Reductions in Fecal Coliform Loads by Sub-Watershed – Allocation Scenario

Table G-1a. Required annual reductions in nonpoint sources in sub watershed MC-01 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	129,677	0.3%	6,484	95%
Pasture[1]	33,419,021	88%	668,380	98%
Loafing Lots	4,001,237	11%	0	100%
Forest	94,133	0.3%	94,133	0%
Residential[2]	270,869	0.7%	13,543	95%
Total	37,914,937	100%	782,540	98%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-1b. Required annual reductions in direct nonpoint sources in sub watershed MC-01 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	14,381	55%	863	94%
Wildlife in stream	11,891	45%	11,891	0%
Straight pipes	0	0%	0	100%
Total	26,272	100%	12,754	51%

Table G-2a. Required annual reductions in nonpoint sources in sub watershed MC-02 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	416,303	0.9%	20,815	95%
Pasture[1]	40,135,548	89%	802,711	98%
Loafing Lots	4,513,909	10%	0	100%
Forest	106,160	0.2%	106,160	0%
Residential[2]	88,317	0.2%	4,416	95%
Total	45,260,237	100%	934,102	98%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-2b. Required annual reductions in direct nonpoint sources in sub watershed MC-02 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	76,819	85%	4,609	94%
Wildlife in stream	13,712	15%	13,712	0%
Straight pipes	0	0%	0	100%
Total	90,531	100%	18,321	80%

Table G-3a. Required annual reductions in nonpoint sources in sub watershed MC-03 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	632,997	1%	31,650	95%
Pasture[1]	47,538,764	98%	950,775	98%
Loafing Lots	0	0%	0	100%
Forest	103,339	0.2%	103,339	0%
Residential[2]	263,893	0.5%	13,195	95%
Total	48,538,994	100%	1,098,959	98%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-3b. Required annual reductions in direct nonpoint sources in sub watershed MC-03 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction

Cattle in stream	133,267	89%	7,996	94%
Wildlife in stream	12,334	8%	12,334	0%
Straight pipes	0	0%	0	100%
Spring Contributions	4,558	3%	4,558	0%
Total	150,159	100%	24,888	83%

Table G-4a. Required annual reductions in nonpoint sources in sub watershed MC-04 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	117,252	0.4%	5,863	95%
Pasture[1]	32,916,748	99%	658,335	98%
Loafing Lots	0	0.00%	0	100%
Forest	6,206	<0.1%	6,206	0%
Residential[2]	73,415	0.2%	3,671	95%
Total	33,113,621	100%	674,075	98%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-4b. Required annual reductions in direct nonpoint sources in sub watershed MC-04 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	0	0%	0	94%
Wildlife in stream	204	100%	204	0%
Straight pipes	0	0%	0	100%
Total	204	100%	204	0%

Table G-5a. Required annual reductions in nonpoint sources in sub watershed MC-05 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	1,309,738	3%	65,487	95%
Pasture[1]	41,435,559	97%	828,711	98%
Loafing Lots	0	0%	0	100%
Forest	119,565	0.3%	119,565	0%
Residential[2]	61,472	0.1%	3,074	95%
Total	42,926,334	100%	1,016,837	98%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-5b. Required annual reductions in direct nonpoint sources in sub watershed MC-05 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	111,664	66%	6,670	94%
Wildlife in stream	14,606	9%	14,606	0%
Straight pipes	0	0%	0	100%
Spring Contributions	42,953	25%	42,953	0%
Total	169,223	100%	64,229	62%

Table G-6a. Required annual reductions in nonpoint sources in sub watershed MC-06 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	565,764	0.4%	28,288	95%
Pasture[1]	142,863,260	99%	2,857,265	98%
Loafing Lots	0	0%	0	100%
Forest	264,124	0.2%	264,124	0%
Residential[2]	728,747	0.5%	36,437	95%
Total	144,421,894	100%	3,186,114	98%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-6b. Required annual reductions in direct nonpoint sources in sub watershed MC-06 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint	TMDL direct nonpoint source allocation load (x 10^8	Percent reduction

		sources	cfu/year)	
Cattle in stream	727,736	92%	43,664	94%
Wildlife in stream	32,074	4%	32,074	0%
Straight pipes	34,041	4%	0	100%
Total	793,852	100%	75,738	90%

Table G-7a. Required annual reductions in nonpoint sources in sub watershed MC-07 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	132,448	0.4%	6,622	95%
Pasture[1]	32,041,139	98.5%	640,823	98%
Loafing Lots	0	0.00%	0	100%
Forest	81,039	0.3%	81,039	0%
Residential[2]	249,721	0.8%	12,486	95%
Total	32,504,348	100%	740,971	98%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-7b. Required annual reductions in direct nonpoint sources in sub watershed MC-07 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	42,322	59%	2,539	94%
Wildlife in stream	10,397	14%	10,397	0%
Straight pipes	0	0%	0	100%
Spring Contributions	19,290	27%	19,290	0%
Total	72,009	100%	32,226	55%

Table G-8a. Required annual reductions in nonpoint sources in sub watershed MC-08 of the Mossy Creek watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	3,351,483	2%	167,574	95%
Pasture[1]	144,778,547	97%	2,895,571	98%
Loafing Lots	0	0%	0	100%
Forest	255,874	0.2%	255,874	0%
Residential[2]	642,365	0.4%	32,118	95%
Total	149,028,268	100%	3,351,137	98%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-8b. Required annual reductions in direct nonpoint sources in sub watershed MC-08 of the Mossy Creek watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	796,660	96%	47,800	94%
Wildlife in stream	29,834	4%	29,834	0%
Straight pipes	0	0%	0	100%
Total	826,493	100%	77,634	91%

Table G-9a. Required annual reductions in nonpoint sources in sub watershed LG-01 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	266,136	1%	13,307	95%
Pasture[1]	21,070,789	97%	1,053,539	95%
Loafing Lots	0	0.00%	0	100%
Forest	51,054	0.2%	51,054	0%
Residential[2]	285,005	1%	199,503	30%
Total	21,672,984	100%	1,317,404	94%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-9b. Required annual reductions in direct nonpoint sources in sub watershed LG-01 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	8,603	87%	86	99%
Wildlife in stream	1,262	13%	883	30%
Total	9,865	100%	969	90%

Table G-10a. Required annual reductions in nonpoint sources in sub watershed LG-02 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	113,489	0.7%	5,674	95%
Pasture[1]	16,227,251	98%	811,363	95%
Loafing Lots	0	0%	0	100%
Forest	38,956	0.2%	38,956	0%
Residential[2]	165,020	1%	115,514	30%
Total	16,544,717	100%	971,507	94%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-10b. Required annual reductions in direct nonpoint sources in sub watershed LG-02 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	26,056	96%	261	99%
Wildlife in stream	1,106	4%	774	30%
Total	27,162	100%	1,035	96%

Table G-11a. Required annual reductions in nonpoint sources in sub watershed LG-03 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	197,280	0.7%	9,864	95%
Pasture[1]	29,214,797	98%	1,460,740	95%
Loafing Lots	0	0%	0	100%
Forest	106,155	0.4%	106,155	0%
Residential[2]	203,481	0.7%	142,437	30%
Total	29,721,713	100%	1,719,195	94%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-11b. Required annual reductions in direct nonpoint sources in sub watershed LG-03 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	73,635	96%	736	99%
Wildlife in stream	2,863	4%	2,004	30%

Total	76,498	100%	2,740	96%

Table G-12a. Required annual reductions in nonpoint sources in sub watershed LG-04 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	1,071,383	2%	53,569	95%
Pasture[1]	56,273,818	98%	2,813,691	95%
Loafing Lots	0	0%	0	100%
Forest	106,155	0.2%	106,155	0%
Residential[2]	119,035	0.2%	83,324	30%
Total	57,570,391	100%	3,056,740	95%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-12b. Required annual reductions in direct nonpoint sources in sub watershed LG-04 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	0	0%	0	99%
Wildlife in stream	520	100%	364	30%
Total	520	100%	364	30%

Table G-13a. Required annual reductions in nonpoint sources in sub watershed LG-05 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8	Percent reduction

			cfu/year)	
Cropland	91,964	2%	4,598	95%
Pasture[1]	5,643,398	98%	282,170	95%
Loafing Lots	0	0%	0	100%
Forest	46,542	0.8%	46,542	0%
Residential[2]	1,644	<0.1%	1,151	30%
Total	5,783,547	100%	334,460	94%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-13b. Required annual reductions in direct nonpoint sources in sub watershed LG-05 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	21,362	95%	214	99%
Wildlife in stream	1,232	5%	863	30%
Total	22,595	100%	1,076	95%

Table G-14a. Required annual reductions in nonpoint sources in sub watershed LG-06 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	1,323,238	1%	66,162	95%
Pasture[1]	105,950,503	89%	5,297,525	95%
Loafing Lots	11,417,429	10%	0	100%
Forest	234,119	0.2%	234,119	0%
Residential[2]	333,108	0.3%	233,176	30%
Total	119,258,397	100%	5,830,982	95%

[1] Includes Pastures 1, 2 and 3
[2] Includes Farmstead, Low and High Density Residential Loads

Table G-14b. Required annual reductions in direct nonpoint sources in sub watershed LG-06 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	160,950	96%	1,610	99%
Wildlife in stream	6,526	4%	4,568	30%
Total	167,476	100%	6,178	96%

Table G-15a. Required annual reductions in nonpoint sources in sub watershed LG-07 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	434,677	0.6%	21,734	95%
Pasture[1]	70,484,337	99%	3,524,217	95%
Loafing Lots	0	0%	0	100%
Forest	163,800	0.2%	163,800	0%
Residential[2]	299,067	0.4%	209,347	30%
Total	71,381,881	100%	3,919,098	95%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-15b. Required annual reductions in direct nonpoint sources in sub watershed LG-07 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	137,954	97%	1,380	99%
Wildlife in stream	4,517	3%	3,162	30%
Total	142,471	100%	4,541	97%

Table G-16a. Required annual reductions in nonpoint sources in sub watershed LG-08 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	721,330	1%	36,066	95%
Pasture[1]	75,152,494	99%	3,757,625	95%
Loafing Lots	0	0%	0	100%
Forest	143,077	0.2%	143,077	0%
Residential[2]	226,090	0.3%	158,263	30%
Total	76,242,990	100%	4,095,031	95%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-16b. Required annual reductions in direct nonpoint sources in sub watershed LG-08 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	128,624	97%	1,286	99%
Wildlife in stream	3,777	3%	2,644	30%
Total	132,401	100%	3,930	97%

Table G-17a. Required annual reductions in nonpoint sources in sub watershed LG-09 of the Long Glade Run watershed.

Land use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cropland	1,499,176	1%	74,959	95%
Pasture[1]	107,263,369	98%	5,363,168	95%
Loafing Lots	0	0%	0	100%
Forest	130,987	0.1%	130,987	0%
Residential[2]	423,800	0.4%	296,660	30%
Total	109,317,330	100%	5,865,774	95%

[1] Includes Pastures 1, 2 and 3

[2] Includes Farmstead, Low and High Density Residential Loads

Table G-17b. Required annual reductions in direct nonpoint sources in sub watershed LG-09 of the Long Glade Run watershed.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent reduction
Cattle in stream	0	0%	0	99%
Wildlife in stream	3,523	100%	2,466	30%
Total	3,523	100%	2,466	30%

APPENDIX H.
Simulated Stream Flow Chart for TMDL Allocation Period

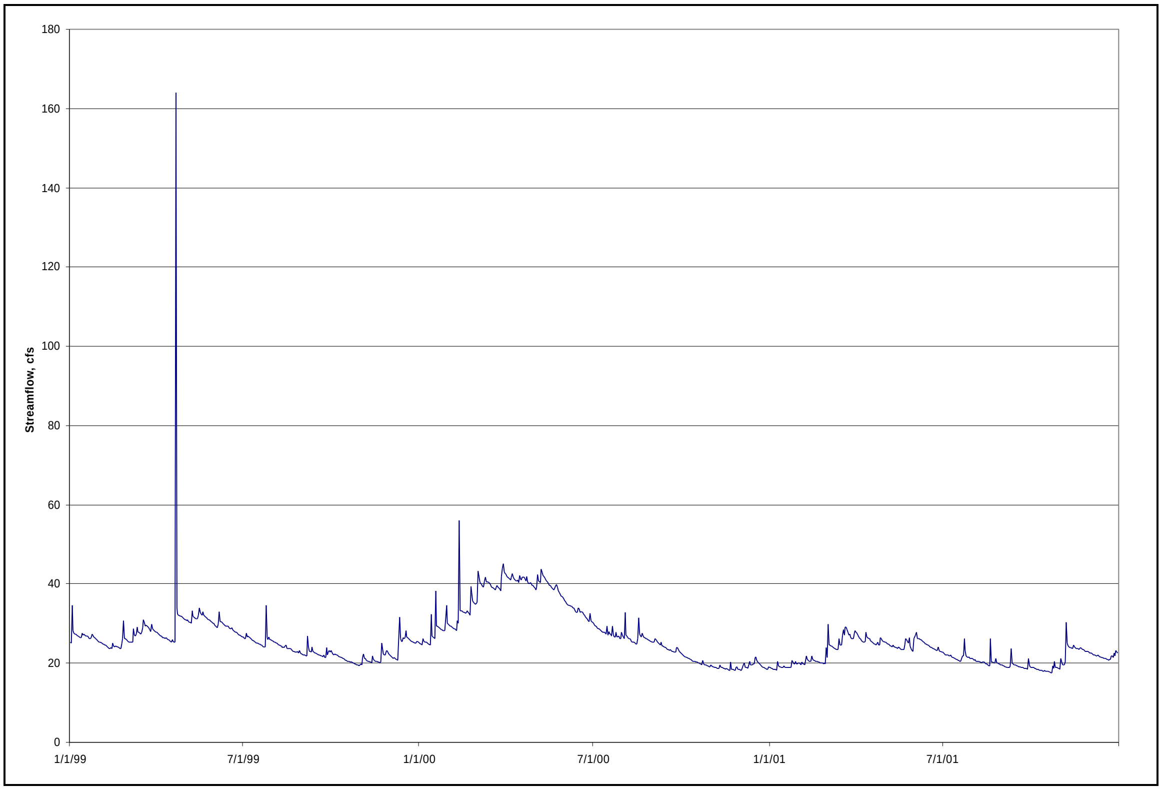

Figure H.1. Simulated Stream Flow for Mossy Creek TMDL Allocation Period.

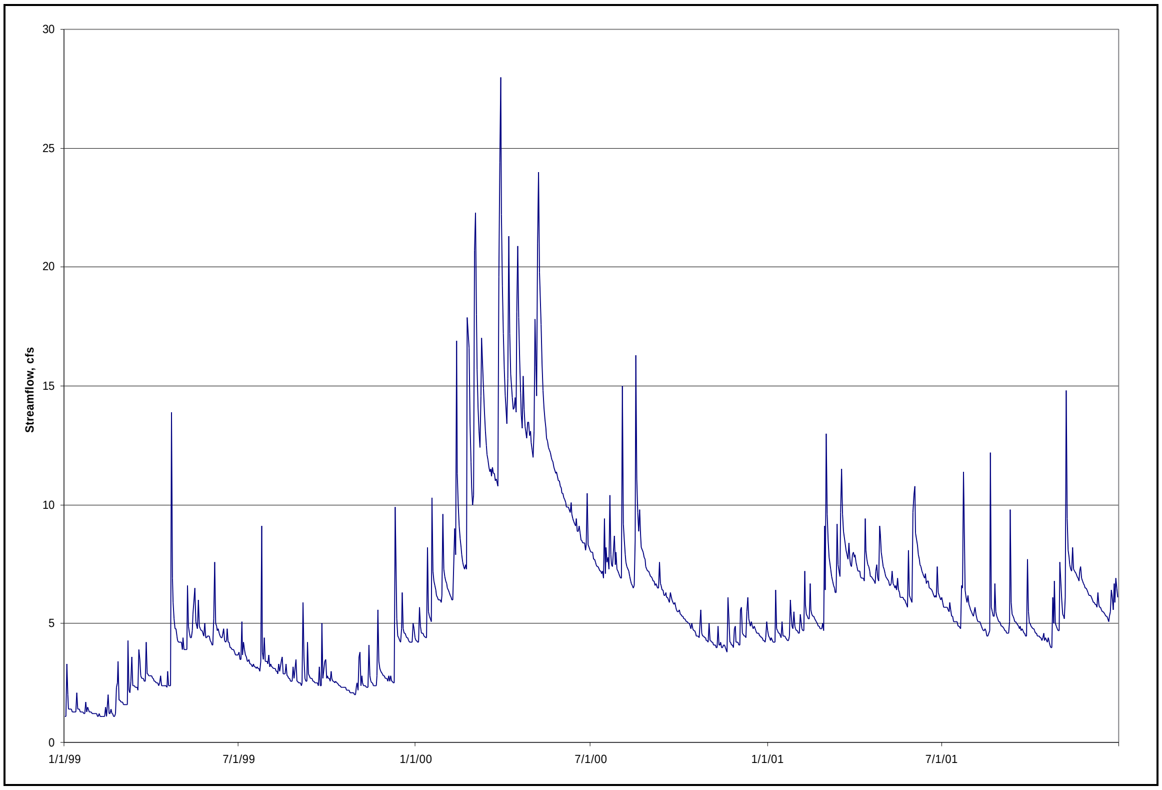

Figure H.2. Simulated Stream Flow for Long Glade Run TMDL Allocation Period.

APPENDIX I.
Observed Fecal Coliform Concentrations and Antecedent Rainfall

Table I.1. Observed fecal coliform and *E. coli* concentrations and antecedent rainfall for the DEQ station 1BMSS001.35 on Mossy Creek.

Date	Fecal Coliform (cfu/100 mL)	*E. coli* (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
7/29/1998	100	--	0.04
8/20/1998	100	--	0.45
9/21/1998	100	--	0.63
10/1/1998	100	--	0.18
11/23/1998	1200	--	0.02
12/21/1998	500	--	0.00
1/27/1999	900	--	0.96
2/25/1999	100	--	0.01
3/31/1999	100	--	0.00
4/21/1999	200	--	0.12
5/19/1999	1000	--	0.41
6/22/1999	8000	--	0.43
7/29/1999	2000	--	1.47
8/12/1999	2700	--	0.06
9/29/1999	8000	--	2.20
11/29/1999	1300	--	0.72
12/20/1999	3100	--	0.24
2/24/2000	25	20	0.19
3/28/2000	250	40	0.14
4/24/2000	550	--	0.53
5/31/2000	2000	800	0.61
6/20/2000	2000	800	1.33
7/27/2000	1000	400	0.92
8/28/2000	2000	800	0.51
9/27/2000	2000	800	1.27
10/19/2000	1900	800	0.01
11/27/2000	220	180	0.41
12/18/2000	1300	800	1.66
1/24/2001	50	120	0.69
2/28/2001	25	10	0.28
4/12/2001	400	100	0.64
5/24/2001	180	150	1.53
6/28/2001	750	580	0.01
7/26/2001	1300	420	0.03
9/5/2001	500	370	0.02
11/28/2001	350	260	0.36
1/22/2002	25	10	0.23
3/4/2002	250	190	0.58
5/30/2002	200	180	0.54
7/25/2002	275	380	1.28

9/3/2002	280	420	0.02

Table I.2. Observed fecal coliform concentrations and antecedent rainfall for the BSE station QMA on Mossy Creek.

Date	Fecal Coliform (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)	Date	Fecal Coliform (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
7/14/1998	1,100	0.00	8/22/2000	160,000	1.20
7/28/1998	800	0.04	9/19/2000	50,000	1.31
8/25/1998	800	0.00	10/16/2000	2,300	0.00
9/22/1998	2,400	0.64	11/14/2000	8,000	0.72
10/20/1998	1,400	0.00	12/12/2000	400	0.42
11/17/1998	2,400	0.00	1/9/2001	300	0.21
12/15/1998	1,300	0.75	2/6/2001	230	0.00
1/12/1999	1,300	0.52	3/8/2001	130	0.10
2/9/1999	5,000	0.20	3/20/2001	20	0.33
3/9/1999	260	0.12	4/3/2001	70	1.36
4/6/1999	700	0.21	4/24/2001	120	0.16
5/4/1999	1,300	0.00	5/1/2001	220	0.00
6/2/1999	2,200	0.00	5/15/2001	230	0.00
6/29/1999	9,000	0.00	5/31/2001	400	0.03
7/27/1999	5,000	1.19	6/12/2001	600	0.06
8/24/1999	16,000	1.39	6/26/2001	700	0.50
9/21/1999	9,000	1.28	7/11/2001	500	0.63
10/19/1999	1,100	0.14	7/25/2001	230	0.00
11/16/1999	800	0.04	8/8/2001	800	0.02
12/14/1999	700	1.37	8/21/2001	1,100	0.06
1/11/2000	300	0.52	9/5/2001	1,400	0.02
2/8/2000	700	0.00	9/19/2001	1,700	0.03
3/6/2000	800	0.01	10/2/2001	230	0.00
4/4/2000	1,100	0.32	10/17/2001	300	0.78
5/2/2000	1,300	0.22	10/29/2001	40	0.00
5/31/2000	170	0.61	11/14/2001	110	0.00
6/27/2000	800	0.89	11/26/2001	800	0.35
7/25/2000	1,300	0.77	12/11/2001	3,000	1.46

Table I.3. Observed fecal coliform and *E. coli* concentrations and antecedent rainfall for the DEQ station 1BLGC000.96 on Long Glade Run

Date	Fecal Coliform (cfu/100 mL)	*E. coli* (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
7/27/1998	2600	--	0.04
10/26/1998	100	--	0.01
2/4/1999	100	--	0.28
4/26/1999	900	--	0.26
8/9/1999	100	--	0.06
10/4/1999	8000	--	1.80
11/9/1999	200	--	0.01
2/24/2000	100	--	0.19
4/5/2000	1200	--	0.32
6/26/2000	500	--	1.04
9/20/2000	8000	--	1.30
11/30/2000	100	--	0.43
3/29/2001	300	--	1.07
6/4/2001	1400	--	0.68
7/26/2001	100	--	0.03
9/5/2001	200	--	0.02
11/28/2001	100	--	0.36
1/22/2002	100	--	0.23
3/4/2002	100	--	0.58
5/30/2002	100	--	0.54
7/25/2002	600	--	1.28
11/25/2002	380	90	0.31
1/22/2003	200	310	0.00
3/19/2003	430	230	0.00

Table I.4. Observed fecal coliform concentrations and antecedent rainfall for the BSE station QLA on Long Glade Run.

Date	Fecal Coliform (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)	Date	Fecal Coliform (cfu/100 mL)	Total Rainfall for Sampling Day and Preceding 5 Days (inches)
7/14/1998	9,000	0.00	7/25/2000	2,400	0.77
7/28/1998	5,000	0.04	8/22/2000	2,400	1.20
8/25/1998	16,000	0.00	9/19/2000	17,000	1.31
9/22/1998	1,700	0.64	10/16/2000	3,000	0.00
10/20/1998	800	0.00	11/14/2000	400	0.72
11/17/1998	1,100	0.00	12/12/2000	2,400	0.42
12/15/1998	1,400	0.75	2/6/2001	1,400	0.00
1/12/1999	2,800	0.52	3/8/2001	90	0.10
2/9/1999	2,400	0.20	3/20/2001	20	0.33
3/9/1999	210	0.12	4/3/2001	120	1.36
4/6/1999	1,100	0.21	4/24/2001	140	0.16
5/4/1999	800	0.00	5/1/2001	300	0.00
6/2/1999	1,100	0.00	5/15/2001	500	0.00
6/29/1999	1,100	0.00	5/31/2001	110	0.03
7/27/1999	1,700	1.19	6/12/2001	170	0.06
8/24/1999	300	1.39	6/26/2001	220	0.50
9/21/1999	3,000	1.28	7/11/2001	230	0.63
10/19/1999	700	0.14	7/25/2001	160,000	0.00
11/16/1999	1,100	0.04	8/21/2001	2,400	0.06
12/14/1999	800	1.37	9/5/2001	3,000	0.02
1/11/2000	230	0.52	9/19/2001	3,500	0.03
2/8/2000	170	0.00	10/2/2001	2,400	0.00
3/6/2000	220	0.01	10/17/2001	80	0.78
4/4/2000	2,200	0.32	10/29/2001	300	0.00
5/2/2000	1,700	0.22	11/14/2001	800	0.00
5/31/2000	800	0.61	11/26/2001	800	0.35
6/27/2000	1,300	0.89	12/11/2001	160,000	1.46

APPENDIX J.
CAFOs in the Mossy Creek and Long Glade Run Watersheds

Table J.1. Permitted Beef CAFO in Mossy Creek.

Permit Number	Integrator	Animal Type	Address	City	Comments
VPG160008	None	Beef	398 Mossy Creek Road	Mt. Solon	

Table J.2. Permitted Poultry CAFOs in Mossy Creek.

Permit Number	Integrator	Bird Type	Address	City	Comments
VPG260031	Pilgrim's Pride	Turkey	398 Mossy Creek Road	Mt. Solon	
VPG260055	Cargill	Turkey	4290 Scenic Highway	Mt. Solon	
VPG260202	Pilgrim's Pride	Turkey	83 Moscow Loop	Mt. Solon	
VPG260286	Cargill	Turkey	5175 Spring Creek Road	Bridgewater	
VPG260308	Cargill	Turkey	827 George Walton Road	Mt. Solon	
VPG260328	Pilgram's Pride	Turkey	1098 Natural Chimneys Road	Mt. Solon	
VPG260538	Georges	Broiler	885 George Waltons Road	Mt. Solon	
VPG260581	Georges	Broiler	163 Pakaho Drive	Mt. Solon	
VPG260703	Cargill	Turkey	151 Bridgewater Road	Bridgewater	
VPG260744	Pilgrim's Pride	Broiler	P.O. Box 37	Mt. Solon	

Table J.3. Permitted Poultry CAFOs in Long Glade Run

PermitNum	Integrator	Bird Type	Address	City	Comments
VPG260041	Cargill	Turkey	5978 Springhill Road	Bridgewater	
VPG260088	Pilgrim's Pride	Turkey	3007 Springhill Road	Staunton	
VPG260213	Cargill	Turkey	6845 Springhill Rd	Bridgewater	
VPG260246	Cargill	Turkey	5904 Spring Hill Road	Bridgewater	
VPG260263	Perdue	Pullet	1204 Mt. Solon Rd	Mt. Solon	
VPG260293	Pilgrim's Pride	Turkey	1180 South High Street	Harrisonburg	
VPG260466	Pilgrim's Pride	Turkey	5256 Springhill Road	Mt. Solon	
VPG260579	Georges	Broiler	48 Centerville Rd.	Bridgewater	
VPG260658	Pilgrim's Pride	Broiler	5490 Springhill Road	Mt Solon	
VPG260698	Pilgrim's Pride	Turkey	5289 Spring Hill Road	Mt. Solon	
VPG260748	Pilgrim's Pride	Turkey	4481 Scenic Highway	Mt. Solon	
VPG260265	Cargill	Turkey	6234 Gardner Lane	Bridgewater	
VPG260505	Georges	Broiler	3722 Spring Creek Road	Bridgewater	

APPENDIX K.
Scenarios for Fivefold Increase in Permitted Discharge Flows

To allow for future growth, scenarios were created for the Mossy Creek and Long Glade Run watersheds in which the point source flows were increased by a factor of 5, while retaining the 200 cfu/100 mL limit on bacteria. This effectively increased the WLA by a factor of 5. Figures K.1 and K.2 display the results for Mossy Creek and Long Glade Run, respectively. The TMDL equations that would represent these situations are included in Table K.1.

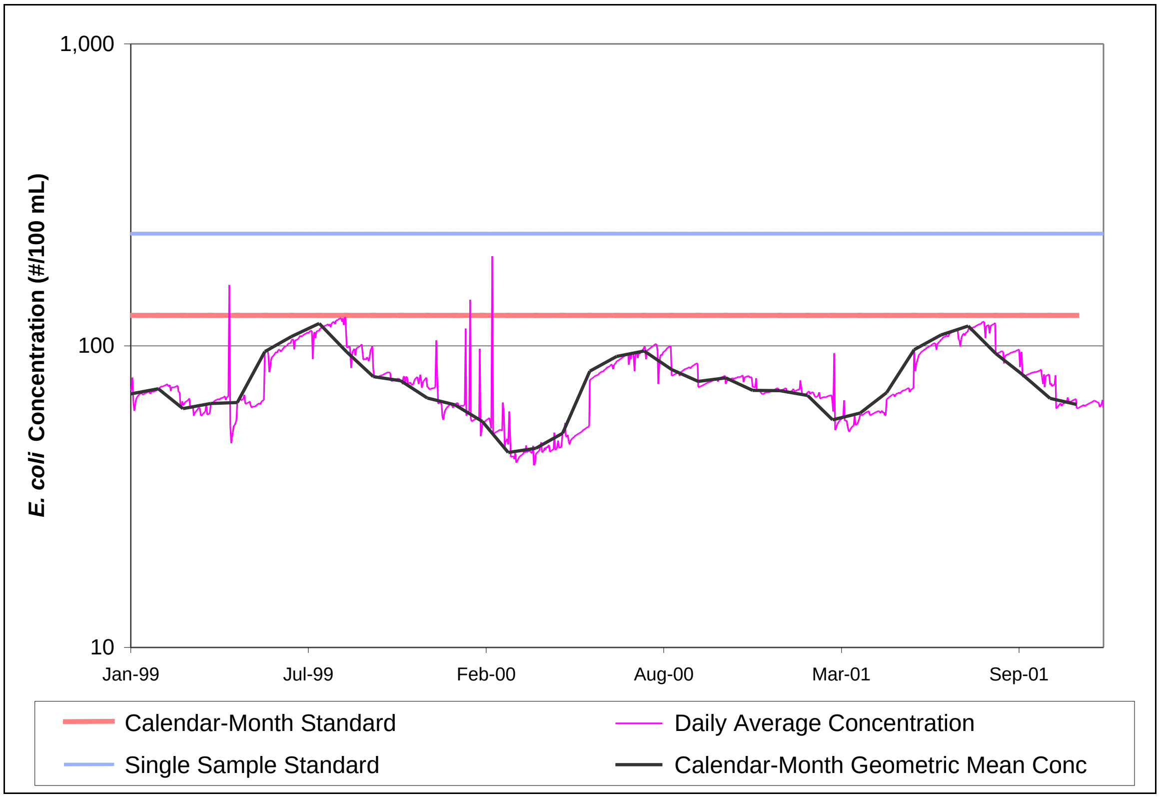

Figure K.1. Daily average and calendar-month geometric mean *E. coli* concentration in the Mossy Creek watershed under the fivefold WLA increase scenario.

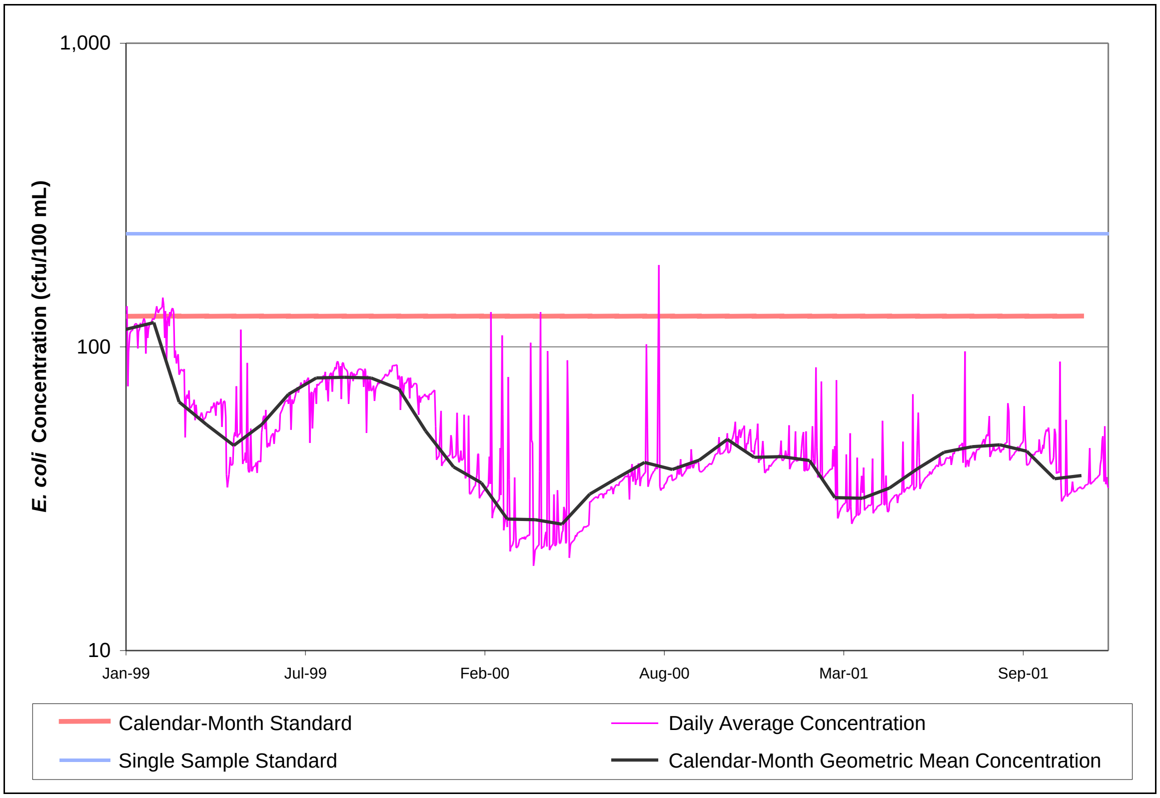

Figure K.2. Daily average and calendar-month geometric mean *E. coli* concentration in the Long Glade Run watershed under the fivefold WLA increase scenario.

Table K.1. Average annual *E. coli* loadings (cfu/year) at the watershed outlet for the Mossy Creek and Long Glade Run watersheds under the fivefold WLA increase scenario.

Watershed	SWLA	SLA	TMDL
Mossy Creek	8.71×10^9	$15{,}196 \times 10^9$	$15{,}925 \times 10^9$
Long Glade Run	26.1×10^9	$2{,}315 \times 10^9$	$2{,}341 \times 10^9$

As can be seen from the graphs, the new scenarios result in no violations of the instantaneous or geometric mean standards. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 200 cfu/100 mL fecal coliform will not cause additional violations of the water quality standards.